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Construction Quality Assurance for Hazardous Waste Land Disposal Facilities

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16. ABSTRACT

Construction quality assurance (CQA) as applied in this document uses scientific and engineering principles and practices to ensure that a hazardous waste land disposal facility is constructed to meet or exceed all design criteria, plans, and specifications. The document covers CQA for hazardous waste landfills, surface impoundments, and wastepiles. The major components of these facilities that are addressed include: foundations, dikes, low-hydraulic-conductivity soil liners, flexible membrane liners, leachate collection systems and final cover systems. The document is intended to complement the Minimum Technology Guidance being issued by EPA's Office of Solid Waste.

At a minimum, the CQA plan should include five elements. These are: 1) responsibility and authority, 2) CQA personnel qualifications, 3) inspection activities, 4) sampling strategies, and 5) documentation.

This document describes these elements in detail and presents information on those activities pertaining to each of the elements that are necessary to ensure that the facility is constructed to meet or exceed the specified design. It is intended for the use of organizations involved in permitting, designing, and constructing hazardous waste land disposal facilities.

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Construction Quality Assurance For Hazardous Waste Land Disposal Facilities

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Task 032

Project Officer

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In cooperation with

Office of Solid Waste and Emergency Response
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DISCLAIMER

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the U.S. Environmental Protection Agency; the permitting and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibly and economically.

This Technical Guidance Document (TGD), prepared in cooperation with the Office of Solid Waste and Emergency Response, presents the elements of a construction quality assurance plan that should be addressed during the permit application procedure for a hazardous waste land disposal facility (i.e., landfill, surface impoundment, wastepile). These elements are: (1) areas of responsibility and lines of authority in executing the construction quality assurance plan; (2) requisite qualifications of construction quality assurance personnel; (3) types of inspections (observations and tests) to be performed as part of construction quality assurance activities; (4) sampling strategies (including sampling frequency, size, and location; acceptance and rejection criteria; and corrective action implementation); and (5) documentation of construction quality assurance activities. The TGD discusses assuring construction quality for several facility components. These components are foundations, dikes, low-permeability soil liners, flexible membrane liners, leachate collection systems, and final cover systems.

This document is intended for use by organizations involved in permitting, designing, and constructing hazardous waste land disposal facilities.

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PREFACE

Subtitle C of the Resource Conservation and Recovery Act (RCRA) requires the U.S. Environmental Protection Agency (EPA) to establish a Federal hazardous waste management program. This program must ensure that hazardous wastes are handled safely from generation until final disposition. EPA issued a series of hazardous waste regulations under Subtitle C of RCRA that are published in Title 40 Code of Federal Regulations (CFR) Parts 260 through 265 and Parts 122 through 124.

Parts 264 and 265 of 40 CFR contain standards applicable to owners/operators of all facilities that treat, store, or dispose of hazardous wastes. Wastes are identified or listed as hazardous under 40 CFR Part 261. Part 264 standards are implemented through permits issued by authorized States or EPA according to 40 CFR Part 122 and Part 124 regulations. Land treatment, storage, and disposal (LTSD) regulations in 40 CFR Part 264 issued on July 26, 1982, and July 15, 1985, establish performance standards for hazardous waste landfills, surface impoundments, land treatment units, and wastepiles. Part 265 standards impose minimum technology requirements on the owners/operators of certain landfills and surface impoundments.

EPA is developing three types of documents to assist preparers and reviewers of permit applications for hazardous waste land disposal facilities. These are RCRA Technical Guidance Documents (TGDs), Permit Guidance Manuals, and Technical Resource Documents (TRDs). Although emphasis is given to hazardous waste facilities, the information presented in these documents may be used for designing, constructing, and operating nonhazardous waste LTSD facilities as well.

The RCRA TGDs present design, construction, and operating specifications or evaluation techniques that generally comply with or demonstrate compliance with the Design and Operating Requirements and the Closure and Post-Closure Requirements of Part 264. The Permit Guidance Manuals are being developed to describe the permit application information the Agency seeks and to provide guidance to applicants and permit writers in addressing information requirements. These manuals will include a discussion of each step in the permitting process and a description of each set of specifications that must be considered for inclusion in the permit.

The TGDs and Permit Guidance Manuals present guidance, not regulations. The do not supersede the regulations promulgated under RCRA and published in the CFR. Instead, they provide recommendations, interpretations, suggestions, and references to additional information that may be used to help interpret the requirements of the regulations. The recommendation of methods, procedures, techniques, or specifications in these manuals and documents is not intended to suggest that other alternatives might not satisfy regulatory requirements.

The TRDs present summaries of state-of-the-art technologies and evaluation techniques determined by the Agency to constitute good engineering designs, practices, and procedures. They support the RCRA TGDs and Permit Guidance Manuals in certain areas by describing current technologies and methods for designing hazardous waste facilities or for evaluating the performance of a facility design. Whereas the RCRA TGDs and Permit Guidance Manuals are directly related to the regulations, the information in the TRDs covers a broader perspective and should not be used to interpret the requirements of the regulations.

This document is a Technical Guidance Document. It was prepared by the Hazardous Waste Engineering Research Laboratory of the Office of Research and Development at the request of and in cooperation with the Office of Solid Waste and Emergency Response. The TGD was first issued as a draft for public comment under the title, "Construction Quality Assurance for Hazardous Waste Land Disposal Facilities" (EPA/530-SW-85-021) dated October 1985. All comments received on the draft TGD have been carefully considered and, if appropriate, changes were made in this final document to address the public's concerns. With issuance of this document, all previous drafts of the TGD are obsolete and should be discarded.

ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) construction quality assurance (CQA) program for hazardous waste land disposal facilities is a two-part program established to ensure that a completed hazardous waste land disposal facility has been constructed to meet or exceed all design criteria, plans, and specifications. The first part of this program will present regulations that specify the use of construction quality assurance at hazardous waste land disposal facilities and is being developed by the Office of Solid Waste and Emergency Response. The second part of this program, addressed by this Technical Guidance Document (TGD), presents the elements of a site-specific CQA plan. This TGD covers CQA for hazardous waste landfills, surface impoundments, and wastepiles. The major components of these facilities that are addressed include foundations, dikes, low-permeability soil liners, flexible membrane liners, leachate collection systems, and final cover systems.

The CQA plan is a site-specific document that should be submitted during the permitting process to satisfy EPA's CQA program. At a minimum, the CQA plan should include five elements, which are briefly summarized below:

- Responsibility and Authority--The responsibility and authority of organizations and key personnel (by title) involved in permitting, designing, and constructing the hazardous waste land disposal facility should be described in the CQA plan.

- CQA Personnel Qualifications--The qualifications of the CQA officer and supporting CQA inspection personnel should be presented in the CQA plan in terms of the training and experience necessary to fulfill their identified responsibilities.

- Inspection Activities--The observations and tests that will be used to ensure that the construction or installation meets or exceeds all design criteria, plans, and specifications for each hazardous waste land disposal facility component should be described in the CQA plan.

- Sampling Strategies--The sampling activities, sample size, methods for determining sample locations, frequency of sampling, acceptance and rejection criteria, and methods for ensuring that corrective measures are implemented as addressed in the design criteria, plans, and specifications should be presented in the CQA plan.

- Documentation--Reporting requirements for CQA activities should be described in detail in the CQA plan. This should include such items as daily summary reports, inspection data sheets, problem identification and corrective measures reports, block evaluation reports, acceptance reports, and final documentation. Provisions for the final storage of all records also should be presented in the CQA plan.

This document describes these elements in detail and presents guidance on those activities pertaining to each of the elements that are necessary to ensure that a completed facility has been constructed to meet or exceed all design criteria, plans, and specifications. It is intended for the use of organizations involved in permitting, designing, and constructing hazardous waste land disposal facilities, including treatment, storage, and disposal facilities (i.e., landfills, surface impoundments, wastepiles).

This report was submitted in fulfillment of Contract No. 68-02-3992, Task 032, by the Research Triangle Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1984 to April 1986. Work was completed as of July 1986.

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1.0 INTRODUCTION

1.1 DOCUMENT PURPOSE

This Technical Guidance Document (TGD) presents guidance for preparing a site-specific construction quality assurance (CQA) plan for a hazardous waste land disposal facility (i.e., landfill, surface impoundment, or wastepile). The guidance describes the elements of a CQA plan that the U.S. Environmental Protection Agency (EPA) believes will ensure that a completed facility has been constructed to meet or exceed all design criteria, plans, and specifications.

EPA believes that a site-specific CQA plan that addresses the components of a hazardous waste land disposal facility is needed and recommends that this plan be included as part of the permit application for such a facility. It should be stressed, however, that methods and procedures described in this document are guidance, not regulations; alternative methods and procedures may be selected by the owner/operator. The hazardous waste land disposal facility components discussed in this document include:

- Foundations
- Dikes
- Low-permeability soil liners
- Flexible membrane liners (FMLs)
- Leachate collection systems (LCSs)
- Final cover systems.

Development of comprehensive information on CQA for these components is being prepared by the Hazardous Waste Engineering Research Laboratory (HWERL) of the Office of Research and Development (ORD) in close cooperation with the Office of Solid Waste and Emergency Response (OSWER). HWERL is using a two-phased approach to meet the goals of EPA's CQA program. This document is the result of Phase One of this approach. Phase Two will develop additional information on construction quality assurance through research that will gather and present information on areas not addressed in detail in Phase One.

1.2 APPLICABILITY TO EXISTING REGULATIONS AND MINIMUM TECHNOLOGY GUIDANCE

The Hazardous and Solid Waste Amendments of 1984 (HSWA) require that the owner/operator of an interim status hazardous waste land disposal facility who constructs a new unit, laterally expands an existing unit, or replaces an existing unit must comply with the minimum technological requirements of §3004(o) with respect to waste received after May 8, 1985.

One aspect of the facility owner/operator's burden of demonstrating good faith compliance with EPA's regulations is presenting evidence that the facility was designed and installed in accordance with those regulations. As part of this demonstration, a site-specific CQA plan should be prepared and submitted to the permitting agency as part of the permit application. This CQA plan should clearly demonstrate that regulatory requirements for the inspection of liners and cover systems (as appropriate) of landfills, surface impoundments, and wastepiles (40 CFR 264.303, 264.226, and 264.254) will be met. The implementation of the CQA plan is demonstrated by CQA documentation. Specific elements that should be included in the CQA plan are identified and addressed in EPA's technical guidance on double liner systems (EPA, 1985) and are discussed in greater detail in Section 2.0 of this document.

A copy of the site-specific CQA plan and CQA documentation should be retained at the facility by the owner/operator. It may be reviewed during a site inspection by the permitting agency and will be the chief means for the facility owner/operator to demonstrate to the permitting agency that EPA's technical guidance for installing a double liner system has been followed. Therefore, it is extremely important that the owner/operator document CQA activities to clearly demonstrate that he followed the EPA regulations and technical guidance on double liner systems when installing the liners and leachate collection systems.

1.3 DOCUMENT USERS

This document is intended for use by organizations involved in permitting, designing, and constructing hazardous waste land disposal facilities.

Permitting agencies (i.e., State agencies and EPA) may use this document when reviewing site-specific CQA plans to help establish the completeness of a submitted CQA plan and to ensure its implementation. This document also may be used by facility owner/operators to make certain that all CQA elements are addressed in their permit applications by helping them critically review a site-specific CQA plan prepared by their supporting organizations (e.g., design engineer, CQA personnel).

A supporting organization preparing a site-specific CQA plan may use this document as a guide, and it will enable them to identify weaknesses and confirm strengths in their own standard CQA programs for hazardous waste land disposal facilities. Construction contractors may use this document as a reference that outlines the inspection activities to which their work may be subjected or as guidance for implementing their own construction quality control plans.

1.4 KEY CONCEPTS

1.4.1 Management of Construction Quality

As applied to this TGD, the management of construction quality is the responsibility of the facility owner/operator and involves using scientific and engineering principles and practices to ensure that a hazardous waste land disposal facility has been constructed to meet or exceed all design criteria, plans, and specifications. This management activity begins prior to construction, continues throughout construction, and ends when the completed facility is accepted by the owner/operator. Managing construction quality involves both construction quality control (CQC), a planned system of inspections that are used to directly monitor and control the quality of a construction project, and construction quality assurance (CQA), a planned system of activities that provide assurance that the facility was constructed as specified in the design.

CQC is performed by the construction contractor(s) and consists of inspections necessary to control the quality of the constructed or installed component. These activities are completely independent of the CQA activities described in this document. Although specific recommendations for CQC practices are beyond the scope of this document, CQC is important as the first step in managing construction quality. CQA is performed independently of CQC. It includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility.

1.4.2 Construction Quality Assurance Program

The CQA program discussed in this document is EPA's approach to CQA for hazardous waste land disposal facilities. This program is divided into two parts: (1) regulations that specify the use of construction quality assurance for hazardous waste land disposal facilities, and (2) guidance that presents the elements of a site-specific CQA plan. This document is the result of Phase One of the second part of EPA's CQA program.

1.4.3 Construction Quality Assurance Plan

This TGD provides guidance for preparing a CQA plan--the facility owner/operator's site-specific written response to EPA's CQA program. The CQA plan should include a detailed description of all CQA activities that will be used to manage construction quality. The CQA plan documents the owner/operator's approach to CQA and should be tailored to the specific facility to be constructed. The facility owner/operator's CQA plan should be included in the permit application, and the permitting agency should review the plan for completeness and confirm that it is implemented.

1.5 DOCUMENT SCOPE AND LIMITATIONS

This document is a compilation of information on construction quality assurance and is limited in its scope and function in the following ways.

First, although the document provides information on state-of-the-art CQA for hazardous waste land disposal facilities, it is not necessarily comprehensive. Researching and evaluating all possible sources of effective CQA guidance and procedures were beyond the scope of this effort. Second, this document should not be construed to present design procedures for hazardous waste land disposal facilities. That remains the responsibility of the design engineer and should be based on site-specific conditions.

2.0 ELEMENTS OF A CONSTRUCTION QUALITY ASSURANCE PLAN

The facility owner/operator should prepare a written CQA plan as part of the permit application. Although the overall content of the CQA plan will depend on the site-specific conditions for the proposed hazardous waste land disposal facility, at a minimum several elements should be included in the plan. These elements are summarized below.

- Responsibility and Authority--The responsibility and authority of organizations and key personnel (by title) involved in permitting, designing, and constructing the hazardous waste land disposal facility should be described in the CQA plan.
- CQA Personnel Qualifications--The qualifications of the CQA officer and supporting CQA inspection personnel should be presented in the CQA plan in terms of the training and experience necessary to fulfill their identified responsibilities.
- Inspection Activities--The observations and tests that will be used to ensure that the construction or installation meets or exceeds all design criteria, plans, and specifications for each hazardous waste land disposal facility component should be described in the CQA plan.
- Sampling Strategies--The sampling activities, sample size, methods for determining sample locations, frequency of sampling, acceptance and rejection criteria, and methods for ensuring that corrective measures are implemented as addressed in the design criteria, plans, and specifications should be presented in the CQA plan.
- Documentation--Reporting requirements for CQA activities should be described in detail in the CQA plan. This should include such items as daily summary reports, inspection data sheets, problem identification and corrective measures reports, block evaluation reports, acceptance reports, and final documentation. Provisions for the final storage of all records also should be presented in the CQA plan.

Each of these elements is described in greater detail in the following subsections.

2.1 RESPONSIBILITY AND AUTHORITY

2.1.1 Organizations Involved in CQA

The principal organizations involved in permitting, designing, and constructing a hazardous waste land disposal facility include the permitting agency, facility owner/operator, design engineer(s), CQA personnel, and construction contractor(s). Except for the permitting agency, the principal organizations will not necessarily be completely independent of each other: the facility owner/operator also may be the construction contractor; the CQA personnel may be employees of the facility owner/operator, of the design engineer, or of an independent firm. Regardless of the relationships among the organizations, it is essential that the areas of responsibility and lines of authority for each organization be clearly delineated as the first element of the CQA plan. This will help establish the necessary lines of communication that will facilitate an effective decisionmaking process during implementation of the site-specific CQA plan. It is also essential that the organization performing CQA operates independently of and is not responsible to the organizations involved in constructing the facility.

2.1.1.1 Permitting Agency--

The permitting agency (i.e., State agencies, EPA) is authorized by law to issue a permit for the construction of a hazardous waste land disposal facility. It is the responsibility of the permitting agency to review the facility owner/operator's permit application, including the site-specific CQA plan, for compliance with the agency's regulations and to make a decision to issue or deny a permit based on this review. The permitting agency will have the responsibility and authority to review and accept or reject any design revisions or requests for variance that are submitted by the facility owner/operator after the permit is issued. The agency also has the responsibility and authority to review all CQA documentation during or after facility construction to confirm that the approved CQA plan was followed and that the facility was constructed as specified in the design.

2.1.1.2 Facility Owner/Operator--

The facility owner/operator is responsible for the design, construction, and operation of the hazardous waste land disposal facility. This responsibility includes complying with the requirements of the permitting agency in order to obtain a permit and assuring the permitting agency, by the submission of CQA documentation, that the facility was constructed as specified in the design. The owner/operator has the authority to select and dismiss organizations charged with design, CQA, and construction activities. The owner/operator also has the authority to accept or reject design plans and specifications, CQA plans, reports and recommendations of the CQA officer, and the materials and workmanship of the contractor. If the owner and operator are different organizations, the facility owner is ultimately responsible for the above activities.

2.1.1.3 Design Engineer--

The design engineer's primary responsibility is to design a hazardous waste land disposal facility that fulfills the operational requirements of the facility owner/operator and the performance requirements of the permitting agency. Design activities may not end until the facility is completed; the design engineer may be requested to change some component designs if unexpected site conditions are encountered or changes in construction methodology occur that could adversely affect facility performance. CQA provides assurance that these unexpected changes or conditions will be detected, documented, and addressed during construction.

Additional responsibility and authority may be delegated to the design engineer by the expressed consent (i.e., a contractual agreement) of the facility owner/operator. Additional responsibility and authority may include formulating and implementing a site-specific CQA plan, periodic review of CQA documentation, modifying construction site activity, and specifying specific corrective measures in cases where deviation from the specified design or failure to meet design criteria, plans, and specifications is detected by CQA personnel.

2.1.1.4 CQA Personnel--

The overall responsibility of the CQA personnel is to perform those activities specified in the CQA plan (e.g., inspection, sampling, documentation). At a minimum, CQA personnel should include a CQA officer and the necessary supporting CQA inspection personnel. The specific responsibilities and authority of each of these individuals should be defined clearly in the CQA plan and in the associated contractual agreements with the facility owner/operator. Specific responsibilities of the CQA officer may include:

- Reviewing design criteria, plans, and specifications for clarity and completeness so that the CQA plan can be implemented

- Educating CQA inspection personnel on CQA requirements and procedures

- Scheduling and coordinating CQA inspection activities

- Directing and supporting the CQA inspection personnel in performing observations and tests by:

    - submitting blind samples (knowns, duplicates, and blanks) for analysis by the CQA inspection personnel and one or more independent laboratories

    - confirming that regular calibration of testing equipment is properly conducted and recorded

    - confirming that the testing equipment, personnel, and procedures do not change over time or making sure that any changes do not adversely impact the inspection process

  - confirming that the test data are accurately recorded and maintained (this may involve selecting reported results and backtracking them to the original observation and test data sheets)
  - verifying that the raw data are properly recorded, validated, reduced, summarized, and interpreted

- Providing to the facility owner/operator reports on the inspection results including:
  - review and interpretation of all data sheets and reports
  - identification of work that the CQA officer believes should be accepted, rejected, or uncovered for observation, or that may require special testing, inspection, or approval
  - rejection of defective work and verification that corrective measures are implemented

- Verifying that a contractor's construction quality control plan is in accordance with the site-specific CQA plan

- At the owner/operator's request, reporting to the contractor results of all observations and tests as the work progresses and interacting with the contractor to provide assistance in modifying the materials and work to comply with the specified design

For the supporting CQA inspection personnel, specific responsibilities may include:

- Performing independent onsite inspection of the work in progress to assess compliance with the facility design criteria, plans, and specifications

- Verifying that the equipment used in testing meets the test requirements and that the tests are conducted according to the standardized procedures defined by the CQA plan

- Reporting to the CQA officer results of all inspections including work that is not of acceptable quality or that fails to meet the specified design.

2.1.1.5 Construction Contractor--

It is the responsibility of the construction contractor to construct the hazardous waste land disposal facility in strict accordance with design criteria, plans, and specifications, using the necessary construction procedures and techniques. This responsibility may be expanded, as part of the contractual agreement with the facility owner/operator, to include formulating and implementing a formal plan for construction quality control.

2.1.2 Project Meetings

Periodic meetings held during the life of the project will strengthen responsibility and authority by enhancing communication between personnel responsible for designing, inspecting, and constructing a hazardous waste land disposal facility. Conducting periodic project meetings is the responsibility of the facility owner/operator; he may delegate that responsibility to one of his supporting organizations (e.g., design engineer). Regardless of who conducts them, periodic project meetings benefit all those involved with the facility by ensuring familiarity with facility design, construction procedures, and any design changes. Examples of the types of meetings that may be held are discussed in the following subsections.

2.1.2.1 Preconstruction CQA Meeting--

A meeting should be held to resolve any uncertainties following the completion of the facility design, completion of the site-specific CQA plan, and award of the construction contract. The facility owner/operator, design engineer, CQA personnel, and construction contractor should all be present. The topics of this meeting include but are not limited to:

- Providing each organization with all relevant CQA documents and supporting information
- Familiarizing each organization with the site-specific CQA plan and its role relative to the design criteria, plans, and specifications
- Determining any changes to the CQA plan that are needed to ensure that the facility will be constructed to meet or exceed the specified design
- Reviewing the responsibilities of each organization
- Reviewing lines of authority and communication for each organization
- Discussing the established procedures or protocol for observations and tests including sampling strategies
- Discussing the established procedures or protocol for handling construction deficiencies, repairs, and retesting
- Reviewing methods for documenting and reporting inspection data
- Reviewing methods for distributing and storing documents and reports
- Reviewing work area security and safety protocol

- Discussing procedures for the location and protection of construction materials and for the prevention of damage of the materials from inclement weather or other adverse events
- Conducting a site walk-around to review construction material and inspection equipment storage locations.

The meeting should be documented by a designated person, and minutes should be transmitted to all parties.

2.1.2.2 Daily Progress Meetings--

A progress meeting should be held daily at the work area just prior to commencement or following completion of work. At a minimum, the meeting should be attended by the construction contractor and the CQA personnel. The purpose of the meeting is to:

- Review the previous day's activities and accomplishments
- Review the work location and activities for the day
- Identify the contractor's personnel and equipment assignments for the day
- Discuss any potential construction problems.

This meeting should be documented by a member of the CQA inspection personnel.

2.1.2.3 Problem or Work Deficiency Meetings--

A special meeting may be held when and if a problem or deficiency is present or likely to occur. At a minimum, the meeting should be attended by the construction contractor and CQA personnel. The purpose of the meeting is to define and resolve a problem or recurring work deficiency in the following manner:

- Define and discuss the problem or deficiency
- Review alternative solutions
- Implement a plan to resolve the problem or deficiency.

The meeting should be documented by a member of the CQA inspection personnel.

2.2 PERSONNEL QUALIFICATIONS

The CQA plan should identify the required qualifications of the CQA officer and the CQA inspection personnel and describe their expected duties.

2.2.1 CQA Officer

The CQA officer is that individual assigned singular responsibility for all aspects of the CQA plan implementation. The CQA officer is responsible to the facility owner/operator and should function independently of the owner/operator, design engineer, and construction contractor. The location of the CQA officer within the overall organizational structure of the project, including the facility owner/operator, design engineer, construction contractor, and permitting agencies, should be clearly described within the CQA plan as noted in the previous discussion on responsibility and authority.

The CQA officer should possess adequate formal academic training in engineering, engineering geology, or closely associated disciplines and sufficient practical, technical, and managerial experience to successfully oversee and implement construction quality assurance activities for hazardous waste land disposal facilities. Many of the responsibilities of a CQA officer may also require that he or she be a registered Professional Engineer or the equivalent. Because the CQA officer may have to interrelate with all levels of personnel involved in the project, good communication skills are essential. The CQA officer should be expected to ensure that communication of all CQA-related matters is conveyed to and acted upon by the affected organizations.

2.2.2 CQA Inspection Personnel

The CQA inspection personnel should possess adequate formal training and sufficient practical technical and administrative experience to execute and record inspection activities successfully. This should include demonstrated knowledge of specific field practices relating to construction techniques used for hazardous waste land disposal facilities, all codes and regulations concerning material and equipment installation, observation and testing procedures, equipment, documentation procedures, and site safety.

2.2.3 Consultants

Authorities in engineering geology, geotechnical engineering, civil engineering, and other technical disciplines may be called in from external organizations in the event of unusual site conditions or inspection results. The CQA plan should present detailed documentation of consultant qualifications when expert technical judgments are obtained and used as a basis for decision in some aspect of construction quality assurance. Expert opinions should not be used as a substitute for objective data collection and interpretation when suitable observations and test procedures are available.

2.3 INSPECTION ACTIVITIES

The third element of the CQA plan should describe the inspection activities (observations and tests) that will be performed by the CQA personnel during hazardous waste land disposal facility construction. The scope of this discussion should address only the construction and installation of all facility components and the manufacture/fabrication of various components and subcomponents when pertinent. It is assumed that the site has been characterized adequately, including evaluation of the hydrogeologic environment. It is also assumed that a site-specific facility design has been prepared that meets regulatory requirements and is acceptable to the facility owner/operator and that this design has been evaluated to ensure its technical correctness and feasibility.

This section addresses the inspection activities that are necessary to ensure that the facility has been constructed to meet or exceed all design criteria, plans, and specifications. The first subsection addresses general preconstruction activities applicable to all facility components. The subsequent subsections address each facility component separately and are further subdivided into sections on preconstruction, construction, and postconstruction inspection activities unique to each component. Specific test methods that may be used to inspect the components of a hazardous waste land disposal facility are listed and referenced in Appendix A.

2.3.1 General Preconstruction Activities

The CQA officer should review for clarity the design drawings and specifications for the hazardous waste land disposal facility to be constructed. The design criteria, plans, and specifications need to be understandable to both the CQA personnel and the construction contractor. If the design is deemed unclear by the CQA officer, it should be returned to the design engineer for clarification or modification.

It may be necessary to include a preconstruction training program for the CQA inspection personnel in the site-specific CQA plan. As stated by the U.S. Department of the Army's Construction Control for Earth and Rock-Fill Dams (1977):

> Preconstruction instructions and training should be given to field inspection personnel to acquaint them with design concepts and to provide them with a clear understanding of expected conditions, methods of construction, and the scope of plans and specifications. This may be done by training sessions, preferably with design personnel present, using a manual of written instructions prepared especially for field personnel, to discuss engineering considerations involved, and to explain control procedures and required results.

The ultimate decision on whether to implement a preconstruction training program rests with the facility owner/operator but may be influenced by recommendations of the supporting organizations.

2.3.2 Foundations

The foundations for hazardous waste land disposal facilities should provide structurally stable subgrades for the overlying facility components. The foundations also should provide satisfactory contact with the overlying liner or other system component. In addition, the foundations should resist settlement, compression, and uplift resulting from internal or external pressures, thereby preventing distortion or rupture of overlying facility components.

It is assumed that, before construction, adequate site investigations have been conducted and the foundation design has been developed to accommodate the expected site conditions. The following subsections describe the inspection activities that are necessary to ensure that a foundation is constructed to meet or exceed the specified design. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.2.1 Preconstruction--

It is especially important for all CQA personnel and the construction contractor(s) to review site investigation information to familiarize themselves with the expected site conditions upon which the facility designs were based. This will help ensure that the CQA personnel will be able to identify any unexpected site conditions that may be encountered during foundation construction. Unexpected site conditions may necessitate modifications of the facility design and construction procedures by the design engineer and the construction contractor to ensure component performance.

2.3.2.2 Construction--

To ensure that the design objectives for the foundation are met, inspection activities during construction of the foundation should include the following (U.S. Army, 1977):

- Observations of soil and rock surfaces for adequate filling of rock joints, clay fractures, or depressions, and removal and filling of sand seams
- Measurements of the depth and slope of the excavation to ensure that it meets design requirements
- Observations to ensure proper placement of any recessed areas for collection or detection pipes and sumps
- Tests and observations to ensure the quality of compacted fill
- Observations of stripping and excavation to ensure that there are no moisture seeps and that all soft, organic, and otherwise undesirable materials are removed. Proof-rolling with heavy equipment can be used to detect soft areas likely to cause settlement. Consistency of the foundation soil may be checked with a hand penetrometer, field vane shear test, or similar device.

In addition, when the foundation is to serve as the lower bedding layer for an FML, inspection activities should include the following:

- Observations to ensure the removal of objects (e.g., roots and rocks) that could penetrate the FML
- Observations to ensure the quality of any specified herbicide and to ensure that it is applied uniformly as specified to the foundation soil

- Observations and tests to ensure that the surface is properly compacted, smooth, uniform, and consistent with design grades.

Inspection activities during foundation construction will help ensure that the facility meets or exceeds the specified design by preventing or detecting the following:

- Sidewall slope failure from moisture seeps, weak foundation soil, or sidewall slopes that are steeper than specified

- Puddling or ponding on the foundation base, improper functioning of the leachate collection systems (LCS) resulting from less than specified bottom slopes, and the unspecified placement of recesses for LCS pipes and sumps

- Flexible membrane liner damage from an improperly prepared foundation (e.g., removing penetrating objects and sterilizing the soil)

- Foundation settlement due to soft areas in the foundation base. Excessive differential settlement can result in distortion or rupture of overlying facility components

- Regions of high permeability in the foundation base, from ungrouted joints or from the presence of high-permeability foundation materials. Permeable zones can compromise the ability of the foundation to serve as an additional barrier to leachate migration and can present pathways for seepage into the facility, causing blowout of the liner during subsequent facility construction.

Continuous visual observation of the construction process is a major means of ensuring that the foundation is constructed to meet or exceed the specified design. Surveying will be necessary to ensure that facility dimensions, side slopes, and bottom slopes are as specified in the design. Visual-manual soil identification techniques and index property tests may be used to monitor foundation soil composition. Cohesive soil consistency may be checked in the field with a penetrometer, a hand-held vane shear device, or other suitable field-expedient measurement device (see Appendix A). These field-expedient methods give only approximate values. They are usually sufficient for construction control or site material verification, but they are not accurate or precise enough to be used for acceptance testing; standard laboratory tests [such as consolidated undrained (CU) or unconsolidated undrained (UU) triaxial or unconfined compression, depending on foundation soil conditions] may be used for acceptance testing. Compaction of soil backfill is controlled as described in Section 2.3.3.2.1. Further information on quality control of foundations may be found in Spigolon and Kelley (1984), USBR (1974), and U.S. Army (1977).

2.3.2.3 Postconstruction--

Foundation completion tests include testing and proof-rolling to ensure uniform foundation soil consistency, visually inspecting foundation surfaces, and surveying to check elevations, slopes, and foundation boundaries.

2.3.3 Dikes

The purpose of a dike in a hazardous waste landfill, surface impoundment, or wastepile is to function as a retaining wall, resisting the lateral forces of the stored wastes. It is the aboveground extension of the foundation, providing support to the overlying facility components. Dikes therefore must be designed, constructed, and maintained with sufficient structural stability to prevent their failure. Dikes also may be used to separate cells for different wastes within a large landfill or surface impoundment.

Dikes may be constructed of soil material that is compacted as necessary to a specified strength, unlike soil liner material, which is compacted for low permeability. Materials other than soil may be used to construct dikes, as long as the design of the dike accommodates the particular material properties and proper installation procedures are followed. Drainage layers and structures may be included in the dike design if conditions warrant control of seepage. (Although seepage through the dike should be prevented by the liner system, a dike must be designed to maintain its integrity if the liner fails and seepage occurs.)

The following subsections describe the inspection activities that are necessary to ensure that a dike is constructed to meet or exceed the specified design. Specific tests mentioned in the following subsections are listed and referenced in Appendix A.

2.3.3.1 Preconstruction--

Preconstruction inspection activities for dikes should include inspection of the prepared foundation and inspection of incoming materials. These activities also may include construction of a test fill.

2.3.3.1.1 Materials inspection--Materials to be used for the dike should be inspected. It is especially important that all dike materials are uniform and as specified to ensure that no soft or structurally weak materials (e.g., organic materials) are included in the dike. Procedures for inspecting soil materials are discussed in Section 2.3.4.1.1.

2.3.3.1.2 Test fill construction--A test fill may be constructed to verify that the specified soil density/moisture content/compactive effort/strength relationships hold for field conditions and to determine construction equipment suitability for dike construction. Test fill compaction is described in Section 2.3.4.1.2. Unlike soil liner test fills, permeability tests are not necessary on dike test fills; strength tests are necessary to confirm the relationship between moisture and density measurements and strength. Tests for shear strength (e.g., consolidated or unconsolidated, undrained triaxial tests or unconfined compressive strength) are appropriate for cohesive soils. Selection of appropriate test method(s) should be based on the expected site-specific conditions of the dike during and after construction. Field-expedient methods of measuring cohesive soil consistency (e.g., penetrometers or vane shear devices) may be used to estimate unconfined compressive strength; however, results of these tests should be confirmed in the test fill using appropriate laboratory methods.

2.3.3.1.3 Foundation preparation--To ensure that the foundation has adequate bearing capacity to support the dike, foundation soil analyses should include strength tests [e.g., unconfined compression or undrained (consolidated or unconsolidated) triaxial tests]; compressive strength correlations with standard penetration tests or vane shear tests may be used for construction control. If soft foundation conditions necessitate excavation and replacement of foundation soils, the excavation of the undesirable material and the placement and compaction of soil in the excavation should be monitored closely and continuously by the CQA inspection personnel. The compacted fill material should be inspected to ensure that it is uniform and as specified. Section 2.3.3.2.1 describes inspection procedures for compacted fill. Foundation inspection procedures are described in more detail in Section 2.3.2.

2.3.3.2 Construction--

Dike construction involves standard earthwork construction practices. Dike construction activities may include compacted fill placement and compaction, drainage system construction, and implementation of erosion control measures. Adequate CQA during dike construction will identify problems resulting from inadequate construction methodologies or materials that could result in dike failure from slope instability, settlement, seepage problems (e.g., piping, pore pressure changes), or erosion.

2.3.3.2.1 Compacted fill construction--Compacted fill may be present in the dike core or may constitute the entire dike. Inspection activities that should be conducted during fill emplacement, conditioning, and compaction include:

- Testing of fill material characteristics (see Section 2.3.4.1.1), permeability, clod size, and frost susceptibility may not be necessary for dike materials
- Measurement of loose lift thickness
- Observation of clod size reduction and material homogenization operations (if applicable)
- Testing of water content (if applicable)
- Observation of type of compaction equipment, number of passes, and uniformity of compaction coverage
- Testing of the density of the compacted fill

- Observation of scarification and connection between compacted fill lifts (if applicable).

Inspection activities for compacted fill, including observations and specific tests, are discussed in more detail in Section 2.3.4.2.

Specifications for compaction of dikes may differ from those for low-permeability soil liners because the former are compacted for strength and the latter are compacted to achieve low permeability. CQA inspection activities are similar, however, except that permeability tests on undisturbed samples are not required for dikes. In addition, strength tests generally are more important for dikes than they are for soil liners. As with soil liners, close visual observation during all phases of construction is a critical aspect of CQA.

2.3.3.2.2 Dike shell construction--Compacted fill may be used to form the dike shells surrounding a compacted core. As with any compacted fill, uniformity of the material is very important. CQA inspection activities that should be conducted during dike shell installation include:

- Testing of fill material characteristics
- Measurement of loose lift thickness
- Testing compacted fill water content and compacted fill density
- Observation of equipment type, number of passes, and routing
- Measurement of dike slopes.

CQA activities for dike shells should be directed toward ensuring that the shear strength and compressibility required by the specified design are achieved.

2.3.3.2.3 Drainage systems installation--Installation procedures and equipment for dike drainage systems are similar to those for leachate collection systems. The observations and tests that are necessary to monitor the installation of drainage system components are discussed in Section 2.3.6.

2.3.3.2.4 Erosion control measures--Erosion control measures are applied to the outer slopes of dikes and may include berms and vegetative covers. Inspection activities necessary for ensuring the quality of erosion control measures are the same as those for topsoil and vegetation subcomponents of cover systems (see Sections 2.3.7.2.7 and 2.3.7.2.8).

2.3.3.3 Postconstruction--

Surveys and visual observations should be conducted to ensure that the dimensions of the completed dike are as specified. Dike slopes are the most important items to check; if slopes are too steep, they may be unstable and eventually could fail. Other items to be checked include berm width (if a berm is part of the dike), crest width, overall height, thickness, and areal dimensions. Finally, vegetative cover, when specified, should be inspected at regular intervals to ensure that vegetation is properly established.

2.3.4 Low-Permeability Soil Liners

The purpose of a low-permeability soil liner depends on the overall liner system design. In the cases of single liners constructed of soil or double liner systems with soil secondary liners, the purpose of the soil liner is to prevent constituent migration through the soil liner. In the case of soil liners used as the lower component of a composite liner, the soil component serves as a protective bedding material for the FML upper component and minimizes the rate of leakage through any breaches in the FML upper component. An objective shared by all low-permeability soil liners is to serve as long-term, structurally stable bases for all overlying materials.

Although natural and manmade soil amendments (e.g., soil-cement, bentonite, lime) may be specified in a soil liner design to enhance the performance of natural soil, CQA inspection activities for specific soil amendments depend on the amendment and site-specific conditions. The CQA guidance presented below for natural soil liners is also applicable to liners constructed of amended soil. Additional CQA activities that are necessary for amended soil liners include inspection of amendments to ensure that their quality is as specified, observations and tests to ensure that the specified amount of soil amendment is mixed uniformly with the natural soil, and observations and tests to ensure that water is uniformly added to the amended soil in the amount necessary to achieve the specified design. ASTM standard methods to test the quality of soil cement materials are available; these tests are referenced in Appendix A of this document. Test methods for other soil amendments are not currently standardized. For soil amendments for which there are no standard tests available, the owner/operator should discuss his approach to testing and other inspection activities with the permitting agency prior to construction.

It is assumed that adequate studies have been conducted before construction to ensure that the low-permeability soil liner design meets or exceeds regulatory requirements. These studies should include soil liner-leachate compatibility testing; laboratory soil density, moisture content, compactive effort, permeability relationships; particle size distribution; Atterberg limits; and those determinations needed for specific designs (e.g., thickness, slope). The following section describes the inspection activities that are necessary to ensure that a low-permeability soil liner is constructed to meet or exceed the specified design. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.4.1 Preconstruction--

Preconstruction CQA activities include inspection of liner materials and test fill compaction.

2.3.4.1.1 Material inspection--It is necessary to inspect all liner materials to ensure that they are uniform and as specified in the design. Material inspection begins as a preconstruction activity and continues throughout the liner construction period. If liner material is obtained onsite, the inspections can be performed as the material is excavated or as it is placed in the storage pile with unsuitable material being rejected. If liner material is obtained offsite, inspection of the soil may be conducted as it arrives at the construction site. Borrow area inspection also may be desirable to ensure that only suitable soil liner material is transported to the site. For borrow areas containing nonuniform materials, it may be necessary for construction personnel to guide excavating equipment to avoid or segregate substandard soil material as it is excavated. CQA inspection personnel should observe segregation operations carefully and continuously to ensure that only suitable material is retained for liner construction.

Initial inspection of the soil can be largely visual; however, CQA inspection personnel must be experienced with visual-manual soil classification techniques. Changes in color or texture can be indicative of a change in soil type or soil moisture content. The soil also should be inspected for roots, stumps, and large rocks. In addition to observations, a sufficient number of samples of the liner material should be tested to ensure that material properties are within the range stated in the specifications. These properties should include at least the following:

- Permeability
- Soil density/moisture content relationships
- Maximum clod size
- Particle size distribution
- Atterberg limits
- Natural water content.

In regions where swelling or other unusual soils are known to occur or when the liner may be exposed to extreme climatic conditions during or following construction, additional properties should be addressed by the testing program.

2.3.4.1.2 Test fill construction--A test fill is a structure used to verify the adequacy of the materials, design, equipment, and construction procedures proposed for the soil liner. Constructing a test fill before full-scale facility construction can minimize the potential dangers and expense of constructing an unacceptable liner. In addition, the test fill is a convenient tool for evaluating the most critical performance standard of the compacted soil liner--permeability.

The primary purpose of a test fill is to verify that the specified soil density, moisture content, and permeability values can be achieved consistently in the full-scale facility with the full-scale compaction equipment and procedures. For these data to be useful, test fill compaction and testing must be well documented, and soil materials, procedures, and equipment used in the test fill must be the same as those used during construction of the full-scale facility.

Several recent studies have indicated that field permeability of a compacted soil liner may be much greater than would be predicted from laboratory permeability tests (Herzog and Morse, 1984; Gordon and Huebner, 1983; Daniel, 1984; Boutell and Donald, 1982). Field permeability tests appear to be much more accurate predictors of the rate at which water will drain through a soil liner than laboratory tests. When used in conjunction with these field tests and a detailed CQA plan, a test fill allows the performance of the full-scale facility to be predicted with the highest degree of confidence currently available.

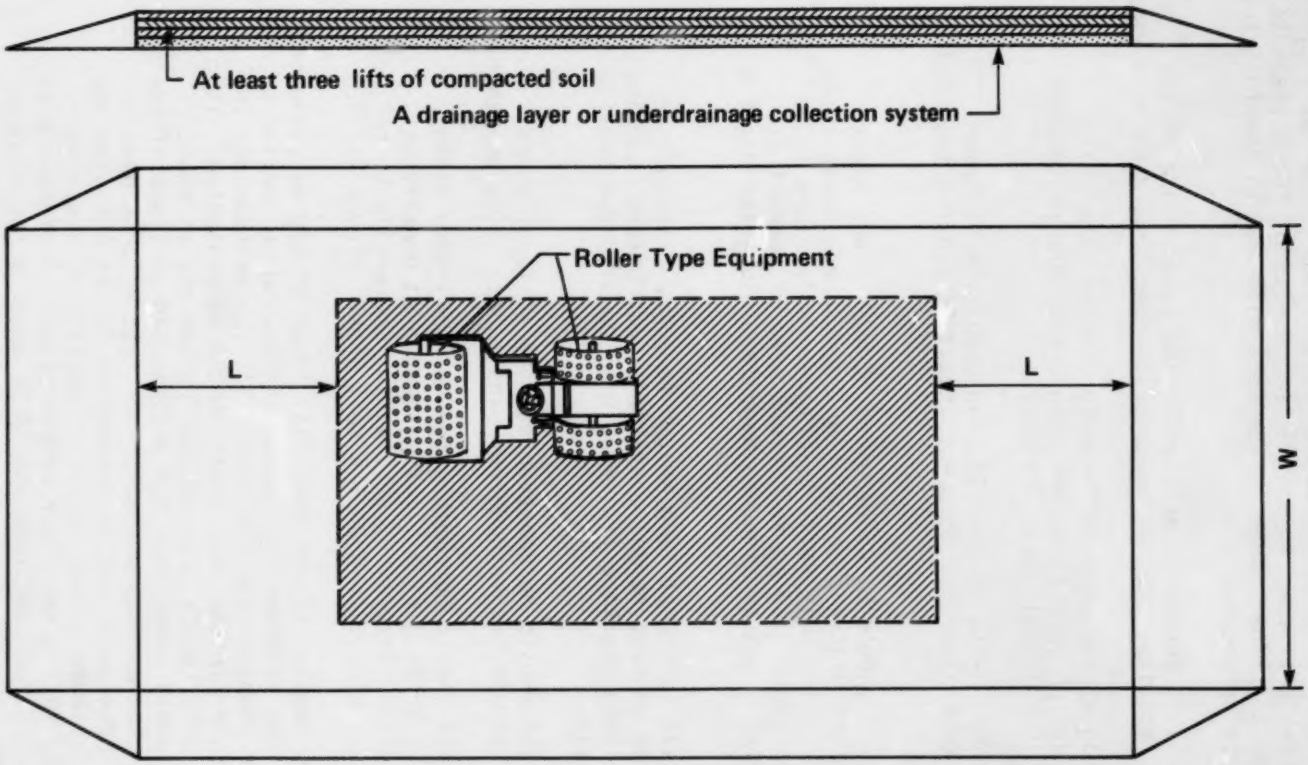
Recently, several field infiltrometers have been developed and tested to measure permeability values (Day and Daniel, 1985; Anderson et al., 1984; Daniel and Trautwein, 1986). Although it is difficult to quantify exactly field permeability values that are substantially less than 1×10^{-7} cm/s (Anderson et al., 1984), it is less difficult to verify simply that the field permeability is 1×10^{-7} cm/s or less (Day and Daniel, 1985).

Field permeability tests conducted on the actual liner can cause substantial delays in construction and result in other problems caused by the prolonged exposure of the liner. Therefore, field permeability tests are usually conducted only on the test fill, thus making it necessary to use data obtained from detailed characterization of the test fill to reach conclusions about the permeability of the full-scale facility soil liner. Such field tests are valid only if the test fill and full-scale facility are constructed according to the same specifications and using the same materials, methodology, and equipment.

The CQA plan should describe all observations and tests to be evaluated on the test fill, including a description of the testing or sampling arrays and replications to be conducted. Based on the parameters evaluated and data collected from the test fill, the CQA plan should specify the tests that will be applied to the full-scale facility liner as surrogates for field permeability tests. Surrogate tests are a group of tests that do not actually measure field permeability but whose results, when considered together, can be used to estimate field permeability and hence can be used to control this parameter during low-permeability soil liner construction. If surrogates for field permeability tests are to be used with a high degree of confidence, data obtained from a test fill evaluation need to show the relationships between the actual measured permeability of areas and lifts across the test fill and the proposed surrogate test results. The CQA plan should describe in detail the actual surrogate observations and tests (e.g., permeability of compacted soil samples, Atterberg limits, particle size distribution, maximum clod size, compacted moisture content, compacted soil density, compactive effort, and penetrometer tests) to be used to control and monitor the construction of the full-scale facility liner. The procedures to be used to relate the results of these tests to field permeability of the liner, both in the test fill and in the full-scale facility, also must be documented.

For the test fill to represent accurately the performance of the proposed full-scale facility, the following guidelines should be followed:

- Construction of the test fill should use the same soil material, design specifications, equipment, and procedures proposed for the full-scale facility.
- All applicable parts of the CQA plan should be followed precisely to monitor and document test fill construction and testing.
- The test fill should be constructed at least four times wider than the widest piece of construction equipment to be used on the full-scale facility (Figure 2-1). This is to ensure that there will be sufficient area to conduct all testing after a buffer area has been left along the edges of the test fill.
- The test fill should be long enough to allow construction equipment to achieve normal operating speed before reaching the area within the test fill that will be used for testing (Figure 2-1).
- The test fill should be constructed with at least three lifts to evaluate the methodology used to tie lifts together.
- The test fill should be constructed to facilitate field permeability testing [i.e., equipped with an underlying unsaturated sand layer or free-draining geotextile to collect and measure drainage through the soil liner (Figure 2-2)].
- Undisturbed samples of the test fill liner should be collected for laboratory permeability tests. Following collection of undisturbed samples from the test fill, the methodology for repairing holes in the soil liner should be evaluated. The evaluation of a repair area should include all of those tests previously identified for undisturbed portions of the test fill. The methods and materials that will be used in the repair process should be documented in the CQA plan and should be followed during repair of testing or sampling holes during full-scale liner construction. Performance of repaired soil liner sections should be equal to or exceed the performance of other liner sections.


At least three lifts of compacted soil
A drainage layer or underdrainage collection system
Roller Type Equipment
L
L
W

L = Distance required for construction equipment to reach normal running speed
W = Distance at least four times wider than the widest piece of construction equipment
▨ = Area to be used for testing

Figure 2-1. Schematic of a test fill.

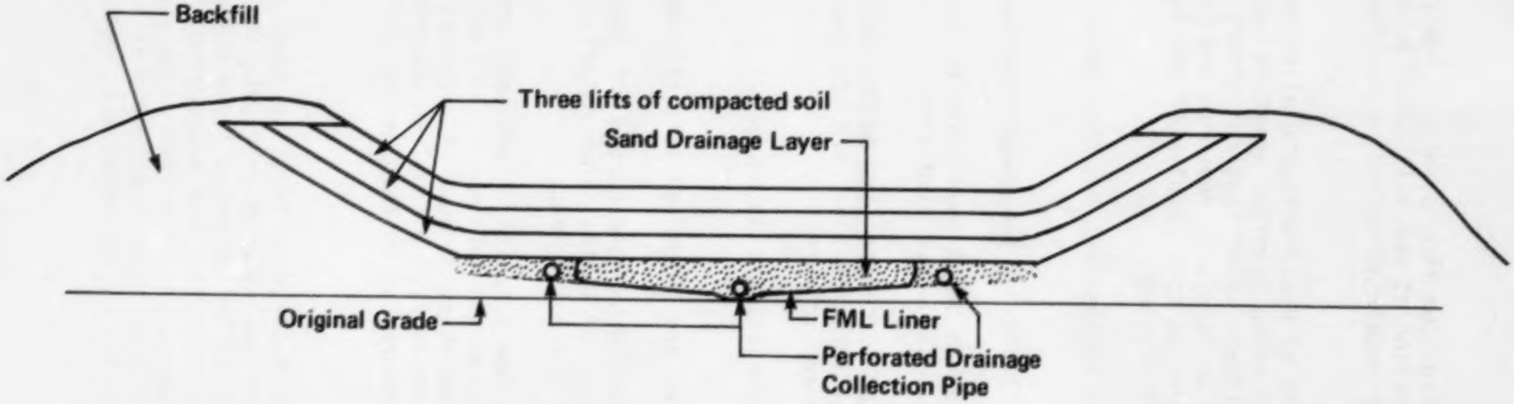

Backfill
Three lifts of compacted soil
Sand Drainage Layer
Original Grade
FML Liner
Perforated Drainage Collection Pipe

Figure 2-2. Example of a test fill equipped to allow quantification of underdrainage.

- The test fill construction should include the removal and replacement of a portion of the soil liner to evaluate the method proposed for repair of defective portions of the full-scale liner.

- The test fill should be constructed to allow determination of the relationship among density, moisture content, and permeability. Field variables that can affect this relationship and that must be carefully measured and controlled in the test fill and during construction of the full-scale liner include the following:

    - the compaction equipment type, configuration, and weight
    - the number of passes of the compaction equipment
    - the method used to break down clods before compaction and the maximum allowable clod size
    - the method used to control and adjust moisture content, including equilibration time, and the quantity of water to be used in any adjustment
    - the speed of the compaction equipment traveling over the liner
    - the uncompacted and compacted lift thicknesses.

Additional test fills should be constructed for each borrow source and whenever significant changes occur in the liner material, equipment, or procedures used to construct the soil liner.

The CQA officer and the CQA inspection personnel should monitor and thoroughly document construction and testing of the test fill. Test fill documentation is extremely important because it provides all organizations involved in facility construction with a complete description of the construction equipment and procedures to be used during full-scale facility construction.

2.3.4.2 Construction--

When construction of the full-scale facility liner begins, questions should not remain about either how or with what materials the liner will be constructed. The suitability of the selected liner material and the adequacy of the construction equipment, construction methodology, and testing procedures will have been confirmed in the test fill. The most important remaining task necessary to construct a soil liner that meets or exceeds the specified design will be to adhere strictly to the materials, equipment, and procedures as verified in the test fill.

There are a number of ways that improper construction practices can result in a soil liner that is unacceptable. Guidelines to identify and correct these improper practices in the field should be provided in the CQA plan. These guidelines should include a combination of both continuous observation by CQA inspection personnel during all periods and phases of liner-related construction activity and frequent use of the tests mentioned in Sections 2.3.4.1.1 and 2.3.4.1.2. Specifically, the CQA plan should address the following:

- Procedures and methods for observing and testing the soil liner materials before and after placement to ensure the following:
    - removal of roots, rocks, rubbish, or off-spec soil from the liner material
    - identification of changes in soil characteristics necessitating a change in construction specifications
    - adequate spreading of liner material to obtain complete coverage and the specified loose lift thickness
    - adequate clod size reduction of liner material
    - spreading and incorporation of soil amendments (if specified) to obtain uniform distribution of the specified amount throughout the liner material
    - adequate spreading and incorporation of water to obtain full penetration through clods and uniform distribution of the specified water content
    - procedures to be followed to adjust the soil moisture content in the event of a significant prolonged rain or drought during construction
    - prevention of significant water loss and desiccation cracking before and after compaction.
- Procedures and methods for observing and testing the soil liner compaction process to ensure the following:
    - use of compaction equipment of the same type, configuration, and weight as used in the test fill
    - use of the same equipment speed and number of equipment passes for compaction as used in the test fill
    - uniformity of coverage by compaction equipment, especially at compacted fill edges, in equipment turnaround areas, and at the tops and bottoms of slopes

- consistent achievement of the specified soil density, water content, and permeability throughout each completed lift

- consistency of permeability values obtained for undisturbed soil liner samples with values obtained for undisturbed samples from the test fill. Undisturbed sample locations should be staggered from lift to lift so holes do not align vertically.

- repair of penetrations or holes resulting from the collection of undisturbed soil samples or the use of density or moisture probes using the same materials and methods used for repairs on the test fill

- adequate tying together of repaired and undisturbed sections of the liner

- use of methods sufficient to tie liner lifts together

- achievement of sufficient liner strength to maintain stable sidewalls and to supply a stable base for supporting overlying materials

- timely placement of protective covers to prevent desiccation of liner material between the installation of lifts or after completion of the liner (where necessary)

- prevention of accidental damage of installed portions of the soil liner by equipment traffic

- achievement of the specified permeability on the soil liner sidewalls.

To ensure the above, it is necessary for the CQA inspection personnel to observe the compaction process (including estimation of compactive effort) continuously and to test the compacted liner at specified intervals using specified tests (see Sections 2.3.4.1.1 and 2.3.4.1.2). The plan for conducting these tests, including methods for determining sampling frequency and location, should be described in detail in the CQA plan. Section 2.4 discusses strategies for determining sampling frequency and location as well as methods for using test data to determine whether to accept or reject completed work. Regardless of the methods used in the development of sampling strategies, they should be described clearly and completely in the CQA plan, along with the rationale for using them.

The compaction process can be affected by climate. Construction specifications often place restrictions on work performed during and just after a rainfall, during very hot or windy conditions, or during freezing weather. For clay soil, wet or freezing weather can alter the soil water content to the point that close control of the compaction process may not be possible. Movement of the construction equipment may be severely affected. As soil temperature falls, more compactive effort must be applied to achieve the same density (Johnson and Sallberg, 1960). Freezing can alter soil structure, causing sloughing of liner materials on the sidewalls or an increase in permeability. In very dry weather, the water content of each surface compacted fill layer can also be altered in a very short time by drying, making continuous watering and blending necessary. Atmospheric conditions should be observed and recorded by CQA inspection personnel, and appropriate actions should be taken when unsuitable weather conditions exist.

Inspection activities during the construction of low-permeability soil liners will help ensure that the facility is constructed as designed by preventing or detecting the following:

- Regions of higher-than-specified liner permeability caused by the use of unspecified materials, inadequate moisture control, insufficient compactive effort, failure to fill test holes properly, failure to adequately tie in repaired and undisturbed liner sections, or construction during periods of freezing temperature
- Less-than-specified liner thickness or coverage from failure to observe, monitor, and control soil placement and compaction operations
- Partings between liner lifts from failure to scarify and control moisture in adjacent lifts
- Leaks around designed liner penetrations resulting from improper sealing and compaction
- Erosion or desiccation of the liner from failure to provide protective cover when construction is interrupted or after liner completion.

2.3.4.3 Postconstruction--

Immediately before placement of any protective cover, the soil liner should be inspected for cracks, holes, defects, or any other features that may increase its field permeability. All defective areas should be removed. If the underlying foundation is defective (soft or wet), then this material also should be removed and the resultant volume should be replaced. Excavated areas of the soil liner should be repaired by the method verified during test fill construction; inspection should ensure that there is continuity between the repaired and undisturbed areas. Special attention should be paid to the final inspections of the sidewall and bottom slopes, liner coverage, liner thickness, and the coverage and integrity of the cover placed over the liner. The completed liner should be protected from desiccation, erosion, and freezing immediately following completion of the uppermost lift.

2.3.5 Flexible Membrane Liners

The purpose of a flexible membrane liner (FML) in a hazardous waste land disposal facility is to prevent the migration of any hazardous constituents into the liner during the period that the facility is in operation and during a 30-year postclosure monitoring period. In addition, FMLs should be compatible with the waste liquid constituents that may contact them and be of sufficient strength and thickness to withstand the forces expected to be encountered during construction and operation.

This section describes the inspection activities necessary to ensure that an FML will meet or exceed all design specifications. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.5.1 Preconstruction--

Preconstruction activities for FMLs include inspection of the raw materials, manufacturing operations, fabrication operations, and final product quality; observations related to transportation, handling, and storage of the membrane; inspection of foundation preparation; and evaluation of the personnel and equipment to be used to install the FML. These activities are discussed in the following subsections.

2.3.5.1.1 FML manufacture--Quality assurance for FML manufacture should begin with the testing of the polymer raw materials. The supplier will generally provide documentation confirming that the raw materials comply with the manufacturers' product properties and performance requirements. However, the manufacturer and the hazardous waste land disposal facility CQA officer also should inspect the polymer raw materials. The specific observations and tests that these individuals may make, depending on the type of raw materials being supplied, include (adapted from Knipschild et al., 1979):

- Density. This property gives an indication of the material's molecular structure and degree of crystallinity, which can be related to mechanical properties such as strength and deformation.

- Melt Flow Index. The constancy of this property within narrow tolerance ranges ensures consistent molecular weight and rheological properties for high density polyethylene. Knowledge of the value for this property is also helpful when selecting production process parameters.

- Relative Solute Viscosity For Hypalon®. The value of this property indicates a polymer's mean molecular weight and its degree of polymerization. These properties affect consistency of processing and the finished product's physical properties.

- Percent Volatile Components For Hypalon®. This test gives a value for the moisture content of the raw material. It is important to control this factor to ensure that a product is free from bubbles and pores.

- Percent Carbon Black. Constant control of the amount and distribution of carbon black in the resin is important to ensure protection against UV radiation.

Additional tests of polymer raw materials may be required by the site-specific CQA plan. These additional tests would be dependent upon the type of polymer being supplied and the environment to which it will be subjected. Standard Number 54 (NSF, 1983) and Koerner (1986) contain descriptions of additional FML test methods.

Other types of raw materials that may be used in the production of specific membrane types include additives and reinforcing materials. These types of materials should be manufactured under the vendor's quality control/ quality assurance program and a certification indicating that they meet the performance specifications should be provided. These additives should also be inspected to confirm that they are the materials that were requested and that they were packaged, labeled, and shipped as specified to prevent damage.

The compounding ingredients used in producing membrane liners should be first quality, virgin material providing durable and effective formulations for liner applications. Clean rework materials containing encapsulated scrim or other fibrous materials should not be used in the manufacture of FMLs. Clean rework materials of the same virgin ingredients generated from the manufacturer's own production may be used by the same manufacturer, provided that the finished products meet the product specifications.

Each manufacturer should have a manufacturing quality control program based on the manufacturing method used and the type of membrane being produced. The hazardous waste land disposal facility CQA officer should obtain a copy of and review the manufacturer's quality control program. This review should include a visit to the production plant for the purpose of viewing quality control activities and laboratory testing facilities. If there are areas where the CQA officer feels the manufacturer's quality control program is weak, he may request that the manufacturer conduct additional tests. The CQA officer may also conduct more tests to verify the manufacturer's product specifications.

The completed FML also should be tested by the manufacturer and these test results verified by the hazardous waste land disposal facility CQA personnel. This phase of CQA is necessary to confirm that the final product meets the liner performance specifications and to establish a "fingerprint" that will be used to ensure that material delivered to the site is as specified (Section 2.3.5.1.3). Examples of finished product specifications that may be tested for various liner types include (Eorgan, 1985; VanderVoort, 1984):

- Thickness
- Tensile properties

- Tear resistance
- Puncture resistance
- Density
- High temperature
- Low temperature
- Dimensional stability
- Resistance to soil burial
- Stress crack resistance
- Oil absorption
- Ozone resistance
- Heat aging
- Volatility loss
- Percent carbon black
- Ultraviolet (UV) resistance
- Chemical resistance
- Specific gravity
- Percent swell
- Ply adhesion
- Scrim characteristics
- Hardness.

Several of the more commonly used physical property test methods are listed in Appendix A and Section 2.3.5.2 of this document as well as in Table VIII-1, p. 407, of "Lining of Waste Impoundment and Disposal Facilities" (EPA, 1983) and in Standard Number 54 (NSF, 1983).

The FML manufacturer and CQA officer should retain a sample of the finished liner from each raw material batch (identified by lot number) for future reference. Appropriate documentation (e.g., product specifications, lot number) should be included with each sample. If problems with the FML occur, it would then be easy to trace the material to the specific batch. When seam samples are retained, it is not necessary to retain a separate FML sample from each of the batches.

2.3.5.1.2 FML fabrication--Factory seaming before shipment to the construction site is necessary for some FML types. Factory seams are used to join smaller liner sections into larger panels or blankets, which will then require fewer field seams. Blankets or panels are then assembled in the field from roll goods according to the designer's or the installer's field layout. Any changes in the layout of factory seams should be approved by the designer and/or installer and the owner/operator. Personnel performing the factory seaming should meet the same reqiurements as those performing the field seaming. The factory seam should be of equal or better quality than that described in Section 2.3.5.2.2.

Factory seams should be 100 percent nondestructively tested using recommended techniques before the FML is shipped from the fabrication plant (Mitchell and Spanner, 1984). Rejected seams should be fully documented and repaired. The CQA officer should review the fabricator's quality control documentation to ensure that proper seaming procedures were followed and the resulting FML seams are of the specified quality. After FML shipment, the CQA officer also should inspect factory seams to ensure that the seam overlap is as specified and that the proper seaming procedure was used. The CQA officer should destructively test several factory seam samples per blanket. In some cases, destructive testing of the blanket's seams may be performed prior to its shipment to a site. It is recommended that this testing be done by an independent laboratory with the quality control documentation being sent directly to the site CQA officer for review. Any necessary repairs to the blanket should be in accordance with approved techniques, and the repaired areas should be nondestructively tested to verify their integrity.

2.3.5.1.3 FML transportation and storage--FMLs are usually shipped in rolls or folded on pallets. When rolls are used, CQA inspection personnel should confirm that the FML has been protected with some type of covering material; often a thick sheet of the same material as the membrane is used. When the membrane is folded on pallets, it should be placed in heavy cardboard or wooden crates before its shipment. The roll or pallet of finished materials should be marked to show the following minimum information (adapted from Schmidt, 1983):

- Name of manufacturer/fabricator
- Product type
- Product thickness
- Manufacturing batch code
- Date of manufacture
- Physical dimensions (length and width)
- Panel number or placement according to the design layout pattern
- Direction for unrolling or unfolding the membrane.

To ensure that the material that was approved in the chemical compatibility test is the material that was delivered to be installed, it should be identified by an appropriate "fingerprint" (Morrison et al., 1982; Haxo, 1983; NSF, 1983). Samples should be obtained and tested from each shipment received at the job site. The shipment should be rejected if the product is not consistent with what was originally approved.

The FML also should be inspected to confirm that it is not damaged and to ensure that any damage is corrected. Damage may include:

- Puncture from nails or splinters
- Tears from operation of equipment or inadequate packaging
- Exposure to temperature extremes resulting in unusable material
- Blocking: the bonding together of adjacent membrane layers, which may be caused by excessive heat
- Crumpling or tearing from inadequate packaging support.

These types of damage may be avoided by careful handling of the FML during preparation for shipment and of the packaged crates and rolls of materials.

When damage to a crate or roll cover has occurred, careful examination of the underlying material by CQA inspection personnel is required. If damage is found, CQA inspection personnel should carefully examine the entire shipment for damage.

Onsite storage of the synthetic membrane liner should be in a secure area with provisions for shelter from adverse weather and should be as brief as possible. This helps avoid damage caused by the following:

- UV light
- Heavy winds or precipitation
- Temperature extremes [i.e., loss of plasticizers in polyvinyl chloride (PVC), curing and adhesion of adjacent surfaces of chlorosulfonated polyethylene, and creation of permanent folds or wrinkles in certain liner types]
- Vandals.

2.3.5.1.4 Lower bedding layer placement--The observations and tests necessary to ensure that an adequate FML lower bedding layer is provided are discussed in Section 2.3.2.2. Prior to FML placement, it is extremely important to inspect visually the bedding layer surface to confirm that it is free from clods of soil, rocks, roots, sudden or sharp changes of grade, and standing water. CQA inspection personnel also should confirm that the soil has been sterilized when necessary with an approved herbicide using the manufacturers' recommended procedures.

In composite liner systems, the lower FML bedding is the compacted low-permeability soil liner. If the bedding is subject to drying and cracking, precautions should be taken by the facility owner/operator to prevent desiccation. This prevention may be in the form of a temporary liner (e.g., thin plastic cover) or special nonreactive chemicals. If a temporary liner is used, the CQA officer should ensure that it is secure at the edges and that, before the installation of the designed FML, the temporary liner is removed and any soil liner cracks are documented and repaired. If desiccation cracks are observed, the appropriate techniques and specifications for correction should be provided in the design specifications.

2.3.5.2 Construction--

Failure of an FML can result from defective manufacturing and fabrication, improper handling and storage, or poor installation methods. The observations and tests necessary to detect these defects during construction are discussed in the following subsections.

2.3.5.2.1 FML placement--Inspection activities that are necessary and should be documented during liner placement include (adapted from Kastman, 1984):

- Checking delivery tickets and synthetic membrane manufacturers' quality control documentation to verify that the synthetic membrane rolls received onsite meet the project specifications. [In addition, "it is usually good practice to take the identifying labels from each roll or pallet and save them for future reference. Further, the position of each roll or pallet of material should be noted on a final installation drawing. This document can be used as future reference should problems occur" (Schmidt, 1983)]. As an additional check to ensure the quality of the product being delivered, a sample should be taken, "fingerprinted," and that fingerprint should be compared with the fingerprint of the product originally contracted for. If these fingerprints are different, the material should be rejected.

- Observations to ensure that the FML placement plan was followed.

- Observations of the weather conditions (i.e., temperature, humidity, precipitation, and wind) to ensure that they are acceptable for membrane placement and seaming.

- Observations and measurements of the anchor trench to ensure that it is as specified in the design drawings. If the trench is excavated in soil that is susceptible to desiccation, only that trench length that is required for 1 day's work should be excavated. Consideration should be given to using a temporary liner in the trench to prevent desiccation. Trench corners should be rounded to prevent stressing the membrane. Good housekeeping practices should be used in the trenching operation by not allowing any loose soil material in the trench or on the downhill side of the trench. Backfilling of the trench should be performed as soon as possible and compacted with care so as not to damage the FML.

- Observations and tests to confirm that all designed liner penetrations and liner connections are installed as specified. Liner penetrations should be verified for appropriate clamp and caulking use, for appropriate material, for good seaming, and for good housekeeping practices. No sharp bends on foundations (concrete pads) should be allowed. Soil compaction adjacent to concrete pads should be performed as specified to prevent differential settlement.

- Measurements to confirm that required overlaps of adjacent membrane sheets were achieved, that proper temporary anchorage was used (e.g., sand bags or tires), that specified temporary and final seaming materials/techniques were used, and that the blanket was placed in a relaxed (nonstressed) state.

As each synthetic membrane panel is placed, it should be visually inspected for tears, punctures, and thin spots. To accomplish this, the panels should be traversed by CQA inspection personnel in such a way that the entire surface, including all factory seams, is inspected. For synthetic membranes that are fabricated from roll stock widths of about 5 feet, the normal procedure used to detect membrane defects is to walk along each roll stock width and inspect the entire length of the sheet. Any defects should be marked on the synthetic membrane for repair.

The overall quality of a flexible membrane liner installation can be affected by the weather conditions during which it was installed. CQA inspection personnel should be aware of all of these factors and the effects they may have on the specific membrane type and seaming procedure being used. If the weather becomes unacceptable for installation of the liner, the CQA officer should recommend stopping the membrane installation until conditions again become favorable, thus minimizing the potential for unacceptable installation.

Inspection activities during FML placement will help ensure that the completed facility meets or exceeds the design specifications by preventing or detecting the following:

- Liner damage from adverse weather conditions, inadequate temporary anchoring, or rough handling

- Improper liner placement (if the placement plan is not followed) and, as a result, inadequate coverage with the available materials or an excess number of field seams results

- Inadequate sheet overlap, possibly resulting in poor quality seams
- Nonwelded or nonseamed sections
- Inadequate seam strength.

2.3.5.2.2 FML seaming--Inspection activities that should be documented during field seaming operations include:

- Observations to ensure that the membrane is free from dirt, dust, and moisture
- Observations to ensure that the seaming materials and equipment are as specified.
- Observations and tests to ensure that a firm foundation is available for seaming
- Observations of weather conditions (e.g., temperature, humidity, wind) to ensure that they are acceptable for seaming
- Measurements of temperatures, pressures, and speed of seaming, when applicable, to ensure that they are as specified (e.g., gages and dials should be checked and readings recorded)
- Measurements of the curing time between seaming and seam testing to ensure that it is as specified (when applicable)
- Observations to ensure that the membrane is not damaged by equipment or personnel during the seaming process.

Inspection activities help ensure that the completed facility meets or exceeds the specified design by preventing and detecting the following:

- Seam gaps or weak spots resulting from the presence of dirt or dust
- Less-than-specified seam strength resulting from the use of unspecified materials, improperly operating equipment, insufficient pressure, ambient temperature extremes, or insufficient dwell time
- Liner damage caused by cleaning or bonding solvents and seaming equipment. Liner damage may also result from walking on the membrane while wearing improper footwear or from the improper disposal of cigarette butts.

After field seams are installed, they should be inspected to ensure that a homogeneous bond was formed. Different nondestructive inspection methods (in addition to visual observations) are available for testing seams in the field, depending on the type of liner material being placed (Mitchell and Spanner, 1984):

- Nondestructive tests should be performed on 100 percent of the field seams. Failed seams should be recorded as to location and seaming crew. The data should be reviewed for possible patterns. Repairs should be made in accordance with approved techniques and retested to verify their integrity.

- Destructive seam testing should be performed at locations and frequencies as selected by the CQA inspection personnel. A minimum number and location per seam length per seam crew should be established. If different seaming techniques are used, additional tests per seaming type should be added. Additional test locations may be necessary at the CQA officer's discretion. These locations may be based on suspicion of contamination by dirt or moisture, change in seaming materials, increase in failed nondestructive tests, and other causes that could result in unacceptable seams.

- Destructive seam samples should be large enough for the installer to check in the laboratory, for an independent laboratory evaluation, and for site owner archiving. If possible, the seam should be destructively tested in the field at the time of sampling (provided sufficient time has elasped for the seam to cure properly). Proper documentation should follow each seam sample as to location, time, crew, and technique.

- Laboratory testing should be performed in accordance with design specifications with predetermined pass/fail values. Both peel and shear testing should be performed as suggested by Standard Number 54 (NSF, 1983) or ASTM, for the specific material type.

- For field seams that fail, the seam can either be reconstructed between the failed and any previous passed seam location or the installer can go on either side of the failed seam location (10-foot minimum), take another sample, test it and if it passes, reconstruct the seam between the two locations. If it fails, the process should be continued. In all cases acceptable seams must be bounded by two passed test locations.

- All repairs should be performed as soon as possible and in accordance with the design specifications. Each repair should be nondestructively tested for continuity. Documentation of all repairs including location, type, and method used should be made.

2.3.5.2.3 Anchors and seals installation--When a hazardous waste land disposal unit design calls for penetrations (e.g., structures and pipes) in the flexible membrane liner, CQA inspection personnel must ensure that the seals around such penetrations are of sufficient strength and are impermeable to leachate. Specific inspections that should be made on all seals or anchors include:

- Observations to ensure that the materials (i.e., pipe boots and sealing compounds) are compatible with the waste and are as specified
- Observations and tests to ensure that the sealing systems (i.e., pipe boots) were installed as specified (are leak free) and in the proper locations
- Observations to ensure that all objects that may be placed adjacent to the synthetic membrane (i.e., batten bars, soil in an anchor trench, and concrete structures) are smooth and free of objects or conditions that may damage the membrane
- Observations and tests to ensure that all seals and anchors are complete (i.e., no gaps or areas of uncompacted backfill).

Inspection activities during this phase of construction will ensure that the completed facility meets or exceeds all design specifications by preventing or detecting the following:

- Compatibility or corrosion problems from the use of unspecified materials
- Leaks around penetrations or slipping of the membrane from incomplete seals or inadequate compaction of backfill
- Flexible membrane damage from rough edges, sharp corners, or rocks. Membrane damage can also occur from excessive stress placed on the liner because of improper location of sealing and/or anchoring mechanisms.

2.3.5.2.4 Upper bedding layer placement--An upper bedding layer, often referred to as a protective cover, when required over an FML, should be placed as soon as possible after installation to protect the FML from weather conditions, equipment, and vandalism. The covering of the FML, while important and necessary, should not be performed until the FML installation is completed and accepted. However, on very large jobs, it may be necessary to accept and cover portions of the liner prior to completion of the entire liner.

Upon completion of flexible membrane liner installation and seam testing, but prior to placement of the upper bedding layer, the liner should undergo a thorough visual inspection for any damage that may have occurred during installation. If any damaged areas are located, they should be marked and patched using approved repair methods. These patched areas should be nondestructively tested to ensure that they do not leak.

The protective cover is usually soil that is free of rocks, sticks, and other items that could damage the membrane. Inspection activities that should be conducted during protective cover installation include:

- Observations and tests to ensure that the cover material meets specifications
- Observations to ensure that the cover material is free from objects that could damage the liner
- Observations to ensure that the equipment used to place the cover material does not operate directly on the FML and does not puncture or tear the FML
- Measurements to ensure that the entire liner is covered with the specified thickness of cover material.

There are a few standard checks and test methods that can be used, in addition to visual observations, to ensure that a flexible membrane liner's protective cover is installed according to the specified design. These checks include surveying using conventional or laser/electronic instruments to ensure that the layer thickness is as specified. The thickness of the cover layer can also be monitored simply by measuring it with a marked measuring staff. When this method is used, CQA inspection personnel must ensure that the staff does not puncture the underlying liner. The bedding layer soil type may be inspected by using visual-manual soil identification techniques and index property tests. These test procedures are briefly discussed in Section 2.3.4.1.1 and are listed and referenced in Appendix A.

Inspection activities during upper bedding layer placement will help ensure that the following problems will be prevented or detected:

- Liner damage from the use of unspecified materials, equipment or human traffic, or weather conditions
- Insufficient upper bedding layer thickness or coverage.

2.3.5.3 Postconstruction--

To check for leaks in the installed membrane liners of small landfills or surface impoundments, the facility can be filled or partially filled with water and seepage from the site measured after accounting for evaporation. This method is often combined with leachate collection system (LCS) testing and, when feasible, is the best way to ensure that the synthetic liner will function according to specifications after it is put into service, assuming that no waste/liner compatibility problems occur. In the case of double liner systems, this type of testing will be more complex because of the presence of two LCSs.

If the waste facility shows evidence of leakage after filling with water, the leak(s) must be located, repaired, and the FML retested before it can be accepted. Several techniques, including tracer dyes and electrical resistivity, may help to locate the leak(s).

2.3.6 Leachate Collection Systems

The purpose of a primary LCS in a landfill is to minimize the leachate head on the top liner during operation and to remove liquids from the landfill through the postclosure monitoring period. The LCS should be capable of maintaining a leachate head of less than 30 cm (1 foot). The purpose of a secondary LCS (sometimes referred to as a leak detection system) between the two liners of a landfill or surface impoundment is to rapidly detect, collect, and remove liquids entering the system through the postclosure monitoring period.

The following sections describe the inspection activities that are necessary to ensure that a completed LCS is constructed to meet or exceed the specified design. In this document, the individual parts that make up an LCS are referred to as subcomponents. Specific tests referred to in the following sections are listed and referenced in Appendix A.

2.3.6.1 Preconstruction--

Preconstruction activities for an LCS include inspection of all materials and examination of the LCS foundation.

2.3.6.1.1 Material inspection--Observing all LCS subcomponent materials as they are delivered to the site is necessary to confirm and document that these materials conform to the design criteria, plans, and specifications. To accomplish this, inspection activities should include the following:

- Observations to ensure that all synthetic drainage layers and/or synthetic filter layers meet the design specifications.
- Observations and measurements to ensure that the pipes are of the specified size and strength, are constructed of the specified material, and that pipe perforations are sized and spaced as specified.
- Observations and tests to ensure that the soils to be used in the LCS are of the proper size and gradation, do not contain unspecified types of materials, and that specified provisions to keep LCS soils clean during storage, handling, and placement are followed.
- Observations to ensure that all prefabricated structures (e.g., manholes and sumps) are as specified in the design. This should include inspection of any corrosion-resistant coatings to confirm that they are present and without flaws.

- Observations of all mechanical, electrical, and monitoring equipment to ensure that it is as specified in the design. In some cases (e.g., pumps), the specific pieces of equipment can be tested to ensure that they are operational.

- Observations and tests to ensure that, when cast-in-place concrete structures are to be installed, the raw materials supplied and necessary forms are as specified in the design.

2.3.6.1.2 Foundation preparation--An examination of the foundation for the LCS should be performed before construction. In the case of double liner systems, the bedding for both primary and secondary LCSs will be an FML or a low-permeability soil liner depending on the type of facility. Inspection activities should include:

- Measurement of the horizontal and vertical alignment of the foundation to ensure that leachate will flow toward the sump

- Observation of the foundation to ensure that it is free of debris and liquids that would tend to interfere with construction of the LCS.

2.3.6.2 Construction--

An LCS is composed of many separate subcomponents. Each of these subcomponents must be installed as specified in the design to ensure proper component function. The following subsections include discussions of observations and tests that should be performed for each LCS subcomponent.

2.3.6.2.1 Bedding layer placement--To avoid damage to the foundation of the LCS, a bedding layer may be placed before pipe network installation. The bedding layer may be either a granular or manufactured material (i.e., geotextile). Inspection activities that should be performed include:

- Observation of the bedding material to ensure that it is as specified and that it does not contain objects that would damage or alter the underlying foundation

- Measurement of the thickness of the bedding layer to ensure uniformity of layer depth

- Observation of the areal coverage of the bedding layer to ensure that it is the same as that specified in the design. When manufactured materials are used, it should be verified that sheets are joined or connected as specified in the design.

These observations and tests are necessary to ensure that the materials in the bedding layer do not damage the foundation.

2.3.6.2.2 Pipe network installation--The pipe network should be placed according to the specified design. Inspection activities that should be performed during pipe placement and joining include:

- Observations and measurements to ensure that the pipes are placed at specified locations and in specified configurations
- Observations and tests to ensure that pipe grades are as specified
- Observations and tests to ensure that all pipes are joined together as specified
- Observations to ensure that the placement of any filter materials around the pipe proceeds as specified in the design
- Observations and tests to ensure that backfilling and compaction are completed as specified in the design and that, in the process, the pipe network is not damaged.

Adequate CQA during this phase of LCS construction will prevent or detect the following:

- Clogging of the LCS pipes or sections of the pipes from the improper installation of filter materials or from soil-laden site runoff
- Inadequate LCS function from the improper joining of pipes, from the improper placement of pipes, or from mechanical damage to the pipe network.

If the pipes are not adequately protected from fine particle accumulations during the construction phase, it may be necessary to flush the pipe network upon completion to remove sedimentation and debris and to verify that the pipes are open. Standard sewer cleaning equipment can be used to remove objects and debris remaining after simple flushing. If this equipment is unable to pass through the line, it may mean that a section of pipe has been crushed or displaced.

Testing of solid pressure and nonpressure LCS pipes should also be conducted to check for leaks and the structural integrity of the solid pipe network. No standardized test procedures are available to perform the test for nonpressure pipes. The American Water Works Association has developed a method for testing solid pressure pipes (AWWA, 1982).

In some cases, it may be desirable to look at the interior of the pipe to verify its alignment and to confirm that there are no obstructions or debris in the pipe. The procedure consists of pulling a television camera mounted on skids through the pipe and recording the distance from the starting point as the camera moves. The location of any problem can be found by measuring the distance from the starting point. In the case of the pipe used to transport leachate out of the facility, this procedure can be used to identify sources of infiltration.

2.3.6.2.3 Drainage layer placement--

Granular drainage layers--Granular LCS drainage layers are constructed of clean, inorganic, free-draining, granular soils such as sand and gravel. These soils are selected before their use in the LCS on the basis of their grain size distribution.

Some or all of the soil drainage layer may be placed before or after pipe placement. To ensure the quality of this drainage layer, CQA inspection personnel should:

- Test the soil to ensure that it is of the specified particle size and free from excessive amounts of fines or organic materials
- Measure the thickness and observe coverage of each drainage layer lift as it is placed in the LCS
- Observe the compaction process and test the compacted layer to ensure its adequacy
- Survey the completed layer to ensure that specified slopes are obtained
- Observe that the transport of fines by runoff into the LCS is prevented by barriers or filters.

When pipe placement precedes granular soil placement, it is also necessary to monitor soil placement and compaction operations to ensure that the LCS pipes (and the FML) are not damaged or moved by the installation equipment.

CQA inspections during granular drainage layer placement will help ensure the integrity of the facility by preventing or detecting the following:

- Areas of lower than specified drainage layer permeability resulting from the use of unspecified materials or from fines that enter and clog the system
- Less-than-specified layer thickness or coverage
- Damaged and misaligned pipes
- Damage to an underlying FML.

There are several standardized test methods that may be used to monitor the drainage layer materials, placement, and compaction. The material type should be monitored using the methods discussed in Section 2.3.6.1.1. A method for determining the permeability of the installed drainage layer, along with the previously mentioned test methods, is listed and referenced in Appendix A.

Synthetic drainage layers--There are three main types of synthetic drainage materials available for use in LCSs: nets, mats, and geotextile fabrics. These synthetic drainage materials may be used alone or in combination with granular drainage layers to form the LCS for a hazardous waste land disposal facility. For more information on synthetic drainage layer design and construction, see GCA Corp. and E. C. Jordan Co. (1984).

Prior to the placement of geotextiles or synthetic drainage materials, CQA inspection personnel should confirm that these materials are as specified and have not been damaged due to shipping or improper storage. Several standardized tests are available to evaluate specified properties of geotextiles. These include tensile strength, puncture or burst resistance, tear resistance, flexibility, outdoor weatherability, and short-term chemical resistance. For more information on these test methods, including discussions on their applicability, limitations, and proper interpretations, the reader is referred to Horz (1984). Appendix B of Horz (1984) also contains detailed test procedures for fabric permeability and percent open area. There are currently no published standard test methods for either of these properties. CQA inspection personnel also should verify that the surface on which the synthetic drainage layer or geotextile is to be placed has been prepared properly. This may include surveying the slope or grade, inspecting material type and compaction for soils, or inspecting flexible membrane seaming and anchoring.

During the installation of a synthetic drainage layer or a geotextile, the CQA inspection personnel should perform the following inspection activities:

- Observations to ensure that the materials are placed according to the placement plan
- Measurements to ensure that the specified material overlap is achieved
- Observations to ensure that the material is free from wrinkles and folds
- Observations and tests, when required, to ensure that seams are made according to the design specifications
- Observations to ensure that weather conditions are appropriate for placement and that the exposure of the synthetic drainage layers or geotextiles to rain and/or direct sunlight during and after installation is minimized

- Observations to ensure that the material is not damaged during the installation process
- Observations to ensure that barriers or filters are installed to prevent clogging of drainage layers from soil-laden site runoff.

Inspection activities during synthetic drainage layer placement will help ensure that the completed facility meets or exceeds the design specifications by preventing or detecting the following:

- Geotextile or synthetic drainage layer slippage resulting from improper placement or seaming
- Stress damage to the material from improper placement
- Improper material function because of wrinkles in the material, inadequate seam overlap, improperly made seams, clogging of the material by fine particles, or damage to the material from weather conditions, human traffic, or equipment.

2.3.6.2.4 Filter layer placement--The filter layer subcomponents of an LCS may be constructed of granular soils or synthetic materials. In both cases the materials used in the filter layer are selected before construction as part of the facility design.

Soil filter layers--LCS soil filter layer placement quality is checked in much the same way as that for granular drainage layers; observations and tests that should be performed and recorded include:

- Soil tests to ensure that it is of the specified grain size and free of excessive amounts of fines or organic materials
- Observations of the placement process to ensure that it is performed as specified
- Measurements of the thickness of the filter layer to ensure that it is as specified.

These observations and tests are necessary to ensure that areas of the LCS do not become blinded or clogged by fine particles infiltrating the system. If this occurs, the LCS will not function properly, and leachate levels in the facility may exceed regulatory requirements.

Synthetic filter layers--Geotextiles are synthetic products specifically designed to have high permeability and strength characteristics. Geotextile filter layers will retain solid material while allowing liquids to flow into the drainage layer and collection pipes. In this application, the geotextile protects the drainage layer and pipe system from becoming clogged.

Inspection activities that should be conducted during the placement of a geotextile filter layer include:

- Observations of geotextile placement to ensure that the specifications are followed, including coverage of all specified areas and adequate material overlap or seaming

- Observations to ensure that the completed geotextile filter layer or any other system subcomponent is not damaged during placement.

These observations and tests are necessary to ensure that the LCS does not become clogged.

2.3.6.2.5 Sumps and associated structure installation--Sumps and manholes can be manufactured offsite and delivered to the site ready for installation as part of the LCS. The design engineer will usually specify that, at a minimum, the supplier should furnish certification with appropriate documentation that the structures have been fabricated according to the design engineer's specifications. Additional inspection of precast concrete, steel, and fiberglass structures may be needed to confirm the identity and quality of manufactured structures. Inspection activities that should be performed include:

- Observations to ensure that the structures were not damaged during shipment

- Measurements to ensure that the structures are of the specified dimensions and capacity

- Observations to ensure that the structures are made of the specified materials

- Observations to ensure that any corrosion-inhibiting coatings are free from defects such as flaking, scratches, or blisters. If defects are present, manufacturers' specifications for repair should be available.

These observations and tests are necessary to ensure that LCS structures are constructed of specified materials, are of adequate size, and are not damaged. If any of these situations occur, the LCS may not function properly.

Visual observations of manhole and collection tank installation are necessary to ensure that the components are installed as specified in the design and that they are not damaged during the process. Installation of the footings or foundations for these structures also should be observed to ensure that damage to the liner is prevented. Surveying should be performed to confirm that all structures are installed in the proper locations.

In the event that manufactured structures are not appropriate, cast-in-place concrete structures may be constructed. The installation of concrete structures, such as manholes and collection tanks, requires visual inspection of the installation, including cast-in-place procedures, and tests of the concrete that is cast at the LCS site. Observations that should be made include:

- Inspection of formwork to ensure that it is complete and has the specified dimensions
- Inspection of concrete placement operations
- Inspection of the curing process to ensure that a satisfactory moisture content and favorable temperature are maintained.

These inspection activities are necessary to ensure that the resulting structure is of the specified size and strength.

Design specifications for concrete will usually require testing of the type, quality, and gradation of the aggregates; the consistency and air content of fresh concrete; and specimens of the concrete for strength. Grain size distribution tests and visual-manual classification are usually required for the aggregates before their use. Consistency, or slump, of the concrete should be determined to ensure that it conforms with the design specifications. The air content of the freshly mixed concrete can be determined by the pressure method. The compressive strength of samples of concrete can be determined using the strength test.

2.3.6.2.6 Mechanical and electrical equipment installation--Installation of mechanical and electrical equipment such as pumps, valves, motors, liquid-level monitors, and flowmeters is usually the final activity during LCS construction. The CQA inspections that should be performed include:

- Observations of all mechanical and electrical equipment installation to ensure that it is in accordance with the design specifications and manufacturers' recommendations
- Testing of all mechanical and electrical equipment in accordance with manufacturers' instructions and operations manuals. Authorized service representatives of the manufacturers may be present to provide any necessary assistance.

These observations and tests are necessary to ensure that the facility meets or exceeds all design specifications. This will reduce the possibility of equipment failure and leachate head buildup in the LCS.

Inspection of electrical connections for mechanical equipment should be performed by personnel certified by national and/or State licensing agencies to perform electrical work. The visual observations necessary for electrical equipment are the same as those previously discussed for mechanical and monitoring equipment. CQA testing should focus on four major areas: insulation, grounding, equipment, and control circuits.

2.3.6.3 Postconstruction--

Postconstruction inspection of an LCS should include:

- Observations to ensure that all system subcomponents have been installed in the proper locations and according to design and manufacturers' specifications

- Testing to ensure that all pumps operate and that all electrical controls and monitoring equipment perform in accordance with the specified design.

A final performance test for the primary LCS may be included as part of a facility's CQA plan. This test may be conducted by filling all or a portion of the system with a known quantity of water. The water should then be removed from the system and its volume determined. The volume of water remaining is the system's storage volume. If the storage volume is significantly higher than expected, there may be areas of the system that are not draining properly. If this is the case, the entire primary LCS should be inspected to locate the areas that are not draining properly. Where performance testing such as this is difficult, alternative inspection activities are presented in Bass (1986). Corrective measures should then be implemented to ensure that the specified drainage can be obtained.

A final performance test of this type should not be conducted on the secondary LCS as this system must remain dry to enable detection of leaks through the primary liner.

2.3.7 Final Cover Systems

Final cover systems for hazardous waste land disposal facilities are designed to provide long-term minimization of liquid migration and leachate formation in the closed landfill by preventing the infiltration of surface water into the facility for many years and minimizing it thereafter in the absence of damage. Final cover systems also control the venting of gas generated in the facility and isolate the wastes from the surface environment. Final cover systems are constructed in layers, the most important of which are the barrier layers. Other layers are included to protect or to enhance the performance of the barrier layers. A final cover system must be constructed so that it functions with minimum maintenance, promotes drainage and minimizes erosion or abrasion of the cover, accommodates settlement and subsidence so that the cover's integrity is maintained, and has a permeability less than or equal to the permeability of the bottom liner system component with the lowest permeability. In this document, the cover system layers are referred to as subcomponents.

The following subsections describe the quality assurance activities necessary to ensure that a completed final cover system meets or exceeds all design specifications. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.7.1 Preconstruction--

Preconstruction activities for final cover systems include screening incoming materials for the system subcomponents and compacting test fills for the soil barriers. These and other preconstruction activities for each cover system subcomponent are identified below and described in the following sections:

- Low-permeability soil barrier (Section 2.3.4.1)
- Flexible membrane barrier (Section 2.3.5.1)
- Drainage and venting layers (Section 2.3.6.1).

For the topsoil and vegetation subcomponents, it should be verified that sufficient quantities of topsoil, fertilizer, soil conditioners, and seeds are available to complete the topsoil/vegetation cover, and that the quality of these materials is as specified in the design. Topsoil should be characterized for the required agronomic properties (Gilman et al., 1983).

Before facility closure, it may be desirable to plant experimental plots to verify that the proposed vegetation will be tolerant of the expected conditions in the final cover system. Conditions that should be considered include local climate as well as (Gilman et al., 1983):

- Cover soil type, depth, and compaction
- Waste depth, type, age, and compaction
- Surface slope.

2.3.7.2 Construction--

The inspection activities necessary for evaluating the construction quality of the final cover system component are addressed below by subcomponent, beginning with the final cover foundation layer. Many of the activities are the same as for other facility components addressed earlier; e.g., the low-permeability barrier is much the same as the low-permeability soil liner. Inspection activities are referenced to earlier sections as appropriate.

For all cover system subcomponents, CQA personnel should be especially attentive to construction around standpipes, vent pipes, and the perimeter of the compacted fill area. Design requirements may be more restrictive in these areas. In the perimeter area, the cover subcomponents must join the liner subcomponents through a relatively complex design. The CQA officer should be especially cognizant of the perimeter design requirements and the measurements necessary to ensure that these requirements are met.

2.3.7.2.1 Final cover system foundation preparation--Before the construction of the cover foundation layer or overlying cover subcomponents, observation and tests should include an evaluation of the stability of the cover system foundation. This is necessary to minimize the potential for future differential settlement or subsidence and resultant final cover system damage.

Soil materials to be used in the cover system foundation should be observed and tested as necessary to confirm that they meet the specified design. Materials specifications may include a maximum particle size and a requirement that they be free of large objects that could damage or make the placement of the overlying low-permeability soil barrier difficult. The construction materials of any subcomponents that are to be installed with their bases in waste or in the foundation layer (e.g., gas vents) should be inspected for conformance to design specifications.

The cover system foundation should be inspected to ensure that its thickness, coverage, surface slope, density, and bearing strength are as specified in the design.

2.3.7.2.2 Low-permeability soil barrier placement--The low-permeability soil barrier provides a base for the flexible membrane barrier subcomponent of the final cover system and provides long-term minimization of liquid infiltration. It serves as a secondary barrier to infiltration in case the flexible membrane barrier fails.

Before construction of the low-permeability soil barrier subcomponent of the cover system, soil materials should be tested to ensure that they are as specified in the design. Throughout the construction process, testing of incoming soil materials should be done on a per-unit-volume basis, and more frequently when CQA inspection personnel suspect a change in soil properties.

The low-permeability soil barrier is constructed much like the low-permeability soil liner. However, the cover system foundation may have a lower bearing strength than the soil liner foundation, and this may necessitate using different equipment or methodology than that which was used to construct the soil liner. This may necessitate the construction of a test fill utilizing the same materials, equipment, and procedures to be used for constructing the soil barrier to ensure that the required permeabilities can actually be achieved in the field and to determine the relationship between soil density, moisture content, compactive effort, and permeability achieved in the test fill (see Section 2.3.4.1.2). This same relationship then must be obtained during the construction of the low-permeability soil barrier subcomponent. As with compacted low-permeability soil liners, it is necessary to monitor soil type, moisture content, density, compactive effort, lift thickness, clod size, uniformity of compaction, completeness of coverage, and permeability during construction. A more complete discussion of inspection activities for low-permeability soil liners can be found in Section 2.3.4.

Seals around penetrations such as gas vent pipes and LCS standpipes should be tested to ensure that they do not leak. Compaction of the soil around penetrations should be closely observed, and clod size, especially where soil is compacted using hand compactors, must be carefully controlled. It is especially important to inspect the perimeter of the cover, where the low-permeability soil barrier subcomponent joins or overlies the liner system, to ensure that it is installed to conform to the specified design.

After completion of the low-permeability soil barrier subcomponent, the surface slope of the barrier layer should be surveyed to ensure that it is constructed as designed and that no depressions remain into which water will flow and stand. In addition, the soil layer should be inspected to ensure that it provides a suitable base for the overlying flexible membrane barrier.

2.3.7.2.3 Flexible membrane barrier installation--The flexible membrane barrier prevents infiltration of precipitation through the cover and into the underlying waste.

Before installation of the flexible membrane barrier, the membrane materials should be observed and tested to ensure that they are as specified (see Section 2.3.5.1). Field seaming equipment and materials should be examined to ensure that they are as specified in the design and are adequate to do the job. Any other materials, such as hardware for anchoring and sealing the membrane to penetrating objects, should be checked for adherence to design specifications.

The base for the flexible membrane barrier subcomponent (the low-permeability soil barrier subcomponent) should be inspected before membrane installation to ensure that its surface is as smooth as possible and that there are no objects that might damage or penetrate the membrane.

All observations and tests used for FML installation are pertinent to the installation of the flexible membrane barrier final cover system subcomponent. A discussion of inspection activities for flexible membrane liners is presented in Section 2.3.5. CQA personnel should be especially attentive to the vent and standpipe penetrations to ensure the integrity of the connections bonding them to the membrane. Around the perimeter of the final cover system, where it joins the liner system, the installed flexible membrane barrier should be tested to ensure that it is installed to conform to the specified design because this is an area with a relatively high potential for leakage.

2.3.7.2.4 Bedding layer placement--An upper bedding layer may be placed to act as a protective buffer between the flexible membrane barrier subcomponent and the overlying drainage layer. This layer acts to protect the membrane from possible puncture by coarse drainage system materials. Bedding layers may be either a granular material or a synthetic material such as a geotextile. Specific observations and tests to be performed are listed in Section 2.3.5.2.4.

Perhaps the most critical inspection activity during the placement of a bedding layer on top of a flexible membrane is to observe the placement process closely to ensure that the construction equipment does not damage the membrane. Following installation, the surface slope of the bedding layer should be surveyed to ensure that the design slope is achieved.

2.3.7.2.5 Drainage and gas venting layer placement--The drainage layers in a final cover system are designed to conduct away infiltrating precipitation before it can penetrate the barrier layers and to vent gas from the facility to appropriate treatment or collection facilities. The gas discharge layer has a consistency and configuration similar to that of the water drainage layer. Both layer types function to transmit fluid preferentially. The main distinction between them is their position in the cover system. The gas discharge layer is placed below the flexible membrane and low-permeability soil barriers and intercepts gases rising from waste cells and directs them to controlled gas discharge vents. The water drainage layer is located above the barriers to intercept and drain water percolating from the surface and direct it to the runoff control system. Both the gas venting and water drainage layers in a final cover system are similar in design and construction to the LCS and may be composed of granular soils and/or synthetic drainage layers, including geotextiles. See Section 2.3.6.2.3 for a more detailed description of drainage layers.

Current regulations require controlled discharge (collection and/or treatment) of hazardous or nuisance gases from facilities. Controlled discharge of gases accumulating in the facility is necessary because of the potential harm that toxic, combustible, and/or malodorous gas may have on human health and the environment. The gas may be collected at the discharge point and transported for treatment or incineration. Alternatively, devices for removing harmful components from the gas or incinerating the harmful components in place may be devised and installed at gas discharge points. This document does not cover these devices in further detail, as currently there is no guidance for designing or constructing them.

The materials used in the construction of the drainage or venting layer are likely to have restrictive specifications, whether materials are soil or synthetic materials. Preconstruction activities must include an inspection of those materials to make certain that they meet the design specifications. The inspection should continue through the construction period as long as materials continue to be delivered to the site. Other preconstruction activities include inspection of the base for the drainage or gas venting layer to ensure that it is and remains in the condition that was specified in the design. Any protrusions, such as vents and standpipes, should also be inspected for any deviations from design specifications.

The inspection procedures during the construction of the drainage and gas venting layers are much the same as those used in the construction of the LCS at the bottom of the landfill. Those procedures are addressed in detail in Section 2.3.6.2. Inspection activities will include ensuring that the specified thickness and surface slope are achieved and that particle size and permeability are as specified in the design. Observations should be made of the filling process around vents and standpipes to prevent damage or misalignment of those structures.

Inspection of the installation of the drainage layers around the perimeter of the cover system is particularly important, for it is here that the system connects to the surface drainage facilities. It is especially important to ensure that the design specifications, particularly dimensions and slopes, are achieved. In addition, controlled gas discharge or collection systems should be checked for proper installation and function.

2.3.7.2.6 Filter layer placement--The purpose of a filter layer above (or below) a drainage layer is to stop the migration or piping of fine materials that could plug a drainage layer and render it ineffective. The filter layer can be constructed of soil materials or may be a geotextile. Soil layer specifications include particle size range and dry density. Geotextiles may be specified according to apparent opening size.

Inspection activities prior to the construction or installation of the filter layer include inspection of the filter materials to confirm that they meet the design specifications.

During the construction of the filter layer, inspection activities should include monitoring of the particle size (for soil materials) or geotextile type and certification, uniformity of thickness for soil, seaming or overlap for geotextiles, slope of the surface, and coverage (particularly around the perimeter of the cover system). CQA inspection personnel should be particularly aware of the potential for damage to penetrating objects such as vent pipes during the construction process. The perimeter area, where the drainage layer intersects surface drainage, should be closely inspected for adherence to the design specifications. More information on CQA inspection activities for filter layer placement is found in Section 2.3.6.2.4.

2.3.7.2.7 Topsoil layer placement--The topsoil layer is the uppermost component of the cover system. Its functions are to protect the underlying layers from mechanical and frost damage, and (in conjunction with a vegetative cover) to protect against erosion.

Topsoil specifications are likely to include properties (e.g., nutrient and organic content) not required for the other soil components of the facility. Soil specifications typical of the other earthwork components may also be included, however.

Preconstruction inspection activities will include checking topsoil properties against the design specifications and ensuring that deleterious materials are not included. The foundation for the topsoil layer will be the filter layer above the drainage layer. The filter layer should be checked to ensure that it has been constructed to meet or exceed the specified design and that any specified penetrations are intact and properly oriented.

During construction of the topsoil layer, CQA inspection personnel should monitor the uniformity of the application process, observe the placement procedure to ensure that the soil is not overly compacted, and measure the thickness and slope of the topsoil layer. CQA inspection personnel should also ensure that care is taken in the vicinity of vents or other protrusions to prevent damage by construction equipment.

In arid areas of the country, where establishment of vegetation is difficult, erosion protection may be achieved through the use of coarse material (e.g., cobbles, riprap). When these materials are used, the inspection should verify that particle size and placement methodology are as specified in the design.

2.3.7.2.8 Topsoil seeding--Topsoil placement, preparation for seeding, and the seeding may take place in a more or less continuous operation. Inspection before the seeding process should include confirmation that the soil additives and seed are as specified in the design. Tilling depth should be measured, and the application rate of additives should be monitored to confirm that it is as specified in the design. The slope of the final surface of the cover should also be verified to ensure that it meets the design requirement. CQA inspection personnel should verify that all vents and standpipes or any other penetrations through the cover are not damaged by the tilling and additive application processes.

The seeding method also may be specified in the design, and CQA inspection personnel should ensure that the application equipment is appropriate for the job; e.g., if hydromulching is called for, then hydromulching equipment should be available and used. The rate of seed and mulch application, amount and uniformity of coverage, and watering instructions when specified, should be followed carefully. Perimeter areas should be examined to ensure that bare spots are not left inadvertently. If tacked mulch is used, the operation should be observed to ensure that it is as specified.

Timing of seeding is important, particularly for grasses. CQA inspection personnel should ensure that it occurs during the designated period and that the weather is favorable. For example, seeding should not take place during high wind or rain or when the soil is frozen. Description of the inspection activities that should be conducted during final cover system seeding may be found in Gilmam et al. (1983).

2.3.7.3 Postconstruction--

CQA inspection personnel should make a visual check of the completed cover to ensure that it meets the specified design. Slopes should be surveyed, any unusual depressions should be noted and corrected, and the vents and standpipes should be examined for alignment and orientation. The perimeter configuration, including drainage conduits also should be examined for conformance to design specifications.

Inspection of the cover should continue until it is ascertained that a vegetation cover has, in fact, been reasonably well established. Grass and ground cover should be evaluated once a month by a qualified specialist during the first 4 to 6 months following germination (Gilmam et al., 1983).

At that time a final check should be made of the final cover to ensure that it is as specified.

2.4 SAMPLING STRATEGIES

For many materials and construction processes, it is necessary to estimate the quality of the overall material or process from the observed or measured quality of a representative sample that is a small fraction of the total material or process. Examples of these situations include assessment of characteristics of a soil liner (e.g., permeability, moisture content, density, particle size distribution) and destructive testing of FML seams. This section presents information that may be useful in the selection and implementation of an appropriate sampling strategy for evaluating construction quality. It is intended to give the reader an introduction to the concepts and assumptions behind different sampling strategies. It is not intended to be a complete or comprehensive treatment of the subject.

Some of the key characteristics and terms of commonly used sampling strategies that are addressed by this document include:

- Data type. Attribute data [such as dichotomous classifications (defective or acceptable)] are the primary information recorded for sampling units when the major concern is the percentage (or number) of sample units that are defective (i.e., exceed or are less than some prespecified level). Measurement data are collected when the goal is to compute summary statistics (e.g., means, variances, ranges). Selection of the type of sampling strategy (attribute or measurement) is a design function.

- Acceptance/Rejection Criteria. When percentage unacceptable is the statistic of concern, acceptance/rejection criteria are based on the maximum percentage of unacceptable units (or measurements) that can be tolerated. When summary measurements are of concern, these criteria are based on the nominal level (e.g., mean, variance) that is considered satisfactory for a specified measurement (e.g, soil permeability, moisture content). Selection of the appropriate acceptance (or conversely rejection) criteria is a design function.

- Sampling Units (or Blocks). Sampling units or blocks are definite isolated quantities of material or construction work, constant in composition and produced by a uniform process, that are eligible for selection into a sample. Each unit may contain one or more element that can be further selected for measurement (Section 2.4.1).

- Number of Sampling Units and Number of Measurements per Unit. These numbers may be selected on the basis of judgment or determined by statistical methods (Sections 2.4.2.2 and 2.4.2.3).

- Location(s) of Sampling Units and/or Measurements Within Units. Locations for individual sampling units and/or measurements may be selected on the basis of judgment or on a random basis (Sections 2.4.2.1 and 2.4.2.2).

- Treatment of Outliers. Criteria for identifying and rejecting measurements that may be in error, or atypical, may be based on judgment or on statistical methods (Section 2.4.4).
- Corrective Measures. When a sample fails to satisfy the acceptance criteria or a measurement is identified as an outlier by the prespecified criteria, some corrective action must be taken (Section 2.4.5). The actual physical means of correction should be specified by the designer.

The reader should note that not all of these features apply to all sampling strategies.

The current state of knowledge on sampling strategies for hazardous waste land disposal facility CQA is not well-developed enough to enable EPA to recommend a specific approach for designing a sampling strategy. For instance, the measurement error inherent in test methods is an important piece of information when devising a statistical sampling strategy. However, the measurement error associated with certain important test methods (e.g., laboratory and field permeability) is not known. Until more information is available, the selection of appropriate sampling strategies should be conducted with the guidance of knowledgeable engineers and statisticians.

2.4.1 Sampling Units and Sample Elements

The term "sampling unit" or "block," as used herein, refers to a definite, isolated quantity of material, such as soil, of constant composition and produced by essentially the same process, that is presented for inspection, acceptance, and/or measurement. Alternatively, it may be a unit of construction work that is assumed to have been produced by a uniform process. Examples of sample units or blocks might include a portion of a lift of compacted fill, a length of membrane seam, or a section of an exposed face of trench wall. It is characteristic of a block that all variation among measured properties within it is assumed to be random, with no underlying differences between locations in the block. The block may be characterized by a block mean and variance or as acceptable or unacceptable for each measured characteristic.

Block size is established on the basis of judgment of uniformity of materials and construction and on economics of inspection. Generally, materials and construction close together in time or space will be more similar than those far apart. This may be a single day's production, a portion of a day's work, a stockpile of material from a uniform, well-defined source, or a single shipment of offsite material.

For measurement purposes, a sampling unit or block is usually subdivided into a number of sample units or batches, each a small and easily identified unit of length, area, volume, weight, package, or time period. A sample element is that portion of material removed (or tested in place) from each selected sample unit or batch. A sample is a collection of sample elements, such as test bores, truck loads, grid sections, or sections of an FML seam. Each element in the sample is independent from the other elements in the sample, and data are collected for each sample element. The sample may represent a block of construction material or process such as an incoming shipment of offsite material for the purpose of inspection as a basis for judging, or estimating, the quality of the block.

2.4.2 Types of Sampling Strategies

The establishment of sampling methods and of sampling and testing frequency may be based on either judgment or on probabilistic methods using statistical theory (Deming, 1950). Willenbrock (1976) states that, up until the last 10 to 15 years ". . . quality of construction was largely accomplished through semi-artisan techniques and procedures with constant visual inspection," or in other words, judgmental sampling. Judgmental methods are subject to biases and sampling errors (Deming, 1950) dependent on the knowledge, capability, and experience of the specification writers, the CQA inspection personnel, and the CQA officer. These factors cannot be easily evaluated and documented. Methods using statistical theory are more rational, calculable, and documentable than judgmental methods and are recommended where feasible and applicable. Whether judgmental or statistical sampling is to be used, it is imperative that the procedure used is specified clearly and completely in the CQA plan and is an accepted approach to sampling the construction materials or operations being evaluated. The rationale used to select and develop the sampling approach should be explained in the CQA plan.

2.4.2.1 100-Percent Inspection--

The ideal situation is that where the quality of all of the material used for a particular component of a hazardous waste land disposal facility can be assessed by an objective observation or test procedure. Clearly, these procedures are limited to observations and nondestructive tests that are relatively inexpensive in terms of resource and time requirements. Examples of such methods are those tests used for FML seams and anchors, collection system pipe joints, pump function, electrical connections, and final leak detection (filling a facility with water). A less than optimum, but necessary, situation is where the quality of a material is assessed by subjective evaluation (usually visual inspection) of all of the material.

2.4.2.2 Judgmental Sampling--

Judgmental sampling refers to any sampling strategy where decisions concerning sample size, selection scheme, and/or locations are based on other than probabilistic considerations. The objective may be to select typical sample elements to represent a whole process or to identify zones of suspected poor quality. Sampling frequency is often specified by the designer and may be a function of the confidence he has in the CQA personnel. Selection of the sampling location(s) is often left up to CQA inspection personnel or the CQA officer making the entire process dependent on the validity of his judgment.

Two considerations need to be addressed during the selection of sampling locations by judgment. First, CQA personnel must select sample locations that they feel are representative of the quality of the work as a whole so that the inspection results will reflect accurately the as-built conditions. In addition, they must locate samples in regions of questionable construction quality to identify work that does not meet design specifications.

There can be no standardized rules for judgmental sampling simply because such sampling depends on the judgment of the designer, CQA officer, and/or CQA inspection personnel. Because judgmental sampling strategies are based on the experience and opinions of the CQA personnel, sample estimates (e.g., mean, variance, or relationship among variables) may be biased and hence may not represent accurately the overall material or process. There is no practical way to test for or to quantify these inherent biases nor to estimate the level of confidence associated with the sample estimates. For example, with a judgmental sampling scheme, it is not possible to estimate how closely the quality measurement of the sample approximates that of the overall material or process.

2.4.2.3 Statistical Sampling--

There is an inherent, or natural, variability in measurement data for any specified quality characteristic of most materials and components used in construction (Terzaghi and Peck, 1967), including the materials and processes used to construct a hazardous waste land disposal facility. This variability may be attributed to variability in material quality, construction operations, measurement techniques and instrumentation, as well as the overall capabilities of the CQA personnel.

Statistical sampling methods are based on the principles of probability theory and are used to estimate selected characteristics (e.g., mean, variance, percent defective) of the overall material or process (population). The primary differences between these methods and those based on judgment are that sample selection is by an objective random process that reduces the likelihood of selection bias (i.e., every sampling unit has a known likelihood of selection) and provides a means of assessing the magnitude of potential error in the sample estimate(s) (i.e., variability in sample group estimates that would be observed if multiple groups of independent sample elements were selected or the likelihood that the sample estimate does not deviate from the overall characteristic to be estimated by more than some specified amount). However, it should be realized that there is a need for experienced judgment in the selection of appropriate statistical techniques and in the evaluation of data generated by these techniques.

In statistical sampling, a sample unit refers to entities that are enumerated for purposes of sample selection and may or may not be the items that are measured. For example, if a grid is overlaid on a soil liner and grid sections are selected into the sample, the grid sections are the sample units; a single measurement, such as size, might be performed for each grid section or a sample of smaller units (e.g., core sections) might be selected from each grid section for testing. The underlying requirement for a statistical (or random) sample is that all of the units selected into the sample must have a known probability (chance) of selection into the sample. An example of a common approach is to assign a unique serial number to each potential sampling unit in the overall material or process and select serial numbers by some random process such as drawing numbers from a hat or using a random number table.

There are many variations in random sampling strategies that can be used. Some examples are:

- If the soil to be used to line a hazardous waste land disposal facility is known to vary across the borrow source, independent samples might be selected from each area and the results combined by a weighting scheme depending on some property of the differentiating characteristic such as particle size, consistency, or overall density (stratified sampling).

- If it is impractical to enumerate all possible sample items (or points), it may be possible to select a small number of large sample units and then select a sample of measurable elements from each unit. The previously mentioned example of selecting core sections from a sample of grid sections of a soil liner illustrates this type of sampling (two-stage sampling strategy).

- If many loads of soil are being hauled to a site and it is reasonable to assume that the loads are homogeneous relative to a particular characteristic, it may be desirable to examine every nth load after starting with a randomly selected start less than 'n' (systematic sampling).

- If the goal is to assess some characteristic of a compacted soil lift, it may be desirable to overlay the site with a grid pattern and to select grid sections for sampling by randomly selecting coordinates. In this situation, if each section has an equal chance of selection, the plan would be classified as simple random sampling. If instead the plan specified that the selection probabilities be in proportion to some known characteristic such as area of grid section, it would be classified as a proportionate sampling. For example, if some grid sections are twice as large as others, the large sections could be given twice the probability of selection as the small sections. This will ensure that the probability of selection per unit area is the same for all grids and is equivalent to the situation in which all grids are equal and have an equal probability of being selected. The primary caution is that selection probabilities be known in advance or be equal for all units in an area and that an accepted statistical technique be used for selection of random numbers.

The plan used for each evaluation should be tailored to the particular situation and types of sample estimates desired. If the goal is to estimate some characteristic of a completed component or process, a simple random sample design or some modification such as a stratified or two-stage sampling plan should be used. If the goal is to monitor an ongoing operation such as placement of soils by trucks, a systematic sampling strategy may be used, where every nth truck would be examined after a random start. The reason for this selection is that the latter design does not require complete enumeration of the potential sampling units whereas some such enumeration scheme is usually necessary for the other designs. Once the data have been collected from a particular sampling strategy, they must be summarized, analyzed, and presented in a way that is tailored to the sample design that was used.

All statistical sampling designs are based on the principles of simple random sampling. For more information concerning the available sampling designs or their underlying probability and distributional properties and assumptions, see Kish (1967).

2.4.3 Selection of Sample Size

The sample size is the number of sample items whose test outcomes are combined mathematically to estimate population parameters (characteristics of the overall site or process). Sample size may be selected by judgmental or statistical methods. The judgmental method is subjective, based on intuition. Classical statistical methods are based on sample-derived statistics and on judgment-selected confidence levels.

2.4.3.1 Judgmental Method--

The judgmental method depends almost entirely on the intuition of the specifier, presumably based on engineering and materials evaluation experience. All of the comments made earlier, in Section 2.4.2, regarding sampling methods also apply to sample size selection. Judgmental methods result in sample means, sample variances, and variable relationships that may be biased and, therefore, may not accurately represent the overall material or processes. These biases cannot be quantified; thus, the level of confidence associated with sample estimates cannot be estimated for judgmental sampling schemes.

Testing frequency for judgmental sampling schemes is often set to produce a fixed proportion of the population (such as 10 percent) or to yield a prespecified sample size per specified unit of time, distance, area, or volume (e.g., taking samples of FML seams on a per linear foot basis). The sample proportions or sizes are usually established on the basis of judgment and experience from similar construction projects. Sampling schemes are usually used to specify minimum sampling frequencies. These frequencies can be increased to identify potential problem areas where additional tests should be made. Samples ideally should be located where CQA inspection personnel have reason to doubt the quality of materials or workmanship.

Organizations that construct large numbers of similar projects, such as the U.S. Army Corps of Engineers or the U.S. Bureau of Reclamation, often employ judgmental sampling with sampling frequencies based on knowledge from their years of construction experience. Usually a range of sampling frequencies is suggested, with estimates of site- and material-specific variability determining which end of the range to use initially. More intensive sampling may be specified in areas where design specifications are difficult to meet, such as in corners of a landfill or equipment turnaround areas.

Examples of sampling strategies can be found in standard specifications, such as AASHTO (1983) and ASTM (1985b), particularly for sampling and testing of materials. The sampling of a batch, such as a soil stockpile, in which some segregation may have naturally occurred, often involves taking three or more sample items that are blended into a single representative element for analysis.

2.4.3.2 Statistical Methods--

2.4.3.2.1 Simple random sampling--A statistically rational and valid method for selecting sample size is given in ASTM (1985b) E 122-72. The equation for the number of sample units (sample size, n) to include in a sample in order to estimate, with a prescribed precision, the average of some characteristic of a block is:

$$n = (ts/E)^2 \tag{2.1}$$

or, in terms of coefficient of variation

$$n = (tV/e)^2 \tag{2.2}$$

where

n = number of units in the sample

t = probability factor

s = the known or estimated true value of the standard deviation for the overall material or process to be estimated

E = the maximum allowable difference between the estimate to be made from the sample and the result of measuring (by the same methods) all of the units in the overall material or process

$e = E/\bar{X}$, the allowable sampling difference expressed as a percent (or fraction) of $\bar{X}$

$\bar{X}$ = the expected (mean) value of the characteristic being measured

V = coefficient of variation.

The probability factor, t, in equations (2.1) and (2.2) is the standard normal deviate (see ASTM, 1985b, for description) that corresponds to the chosen level of confidence that the sample estimate will not differ from the true value of the "to be estimated" characteristic for the overall material or process by more than the allowable difference (E). For a two-sided test (test for error both above and below the estimated value), the commonly used values of t are 1.96 and 1.64, corresponding to 95 and 90 percent levels of confidence, respectively. For sample sizes less than thirty, the correct t value can be determined iteratively. For a one-sided test (test for error in one direction only), a value of 1.64 corresponding to the 95 percent level is commonly used. For values of t (or z, as indicated in many tables and texts) corresponding to other levels of confidence, see any basic statistics book.

As described in ASTM (1985b) E 122-72, the estimated standard deviation, s, should be derived from previous measurements of standard deviation for the same material or process, and should have been developed from at least 30 measurements. As new data are collected from subunits of the overall material or process, they can be used to supplement or replace the old data (depending on comparability of the new and old data) to further refine the estimate of s and the resulting sample size estimate. If no previous data exist, s can be roughly approximated from background knowledge of the shape of the distribution or by conducting a pilot, or preliminary, study where a small number of measurements are performed on a subset of the overall material or process (possibly on the test fills).

It should be recognized that a sample size determination is an estimate (or best guess) of the minimum quantity sufficient to satisfy stated objectives. Because the estimates are based on historical data or subjective opinions of the underlying distribution and cannot take into account all of the factors that contribute to sample variability, they may not be adequate to produce assessments with the prespecified level of confidence. It is always necessary to recompute confidence levels as part of the ordinary data analysis of the sample data. If the resultant confidence level is not sufficient, it may be necessary or at least desirable to supplement the sample to attain the desired level. As long as the original sample was selected by an accepted random process, the test methods have not changed since the initial sample analysis, and the same sampling scheme used for the original sample is used for the supplement (i.e., every sample unit has an equal likelihood of inclusion in either the original or supplemental samples), it usually will be satisfactory to combine the two samples to reduce variability of the sample estimates and hence increase the confidence level. It should be stressed that the purpose of sample supplementation is to improve estimation precision (i.e., variance of estimates) and not to change point (mean) estimates; usually the effects of supplementation also will result in changed point estimates.

A sample size designed to produce estimates with prespecified reliability or confidence for the overall material or process probably will not be adequate to assess the quality of some subsection where there is a need for separate evaluation. For example, the sample size selected for determining whether the overall clay liner meets the maximum criteria for permeability probably will not be sufficient to assess the permeability of a particular section of the liner where the soil appears to differ from that used in the rest of liner. Therefore, it may be necessary to increase the sample frequency or sample size for a subarea where visual observations of materials or construction operations indicate that the quality of construction is suspect. If these data are to be combined with the rest of the data from the overall site, all data analyses must include an adjustment for the differences in sample selection probabilities between the original and supplemental samples.

2.4.3.2.2 Acceptance sampling--Acceptance sampling is the use of a sample to decide whether a particular section or component of a material or process meets the specified design. The following example assumes that acceptance will be based on measurement results, such as soil permeability. If acceptance is based on attribute data (i.e., each sample element is classified as defective or acceptable), please refer to standard quality control references such as Burr (1976).

The following example illustrates one approach for determining if a clay liner for a proposed hazardous waste land disposal facility satisfies the specified design permeability of at least 10^{-8} cm/s or less. It demonstrates methods for estimating sample size and for developing the sample evaluation scheme to ensure with prescribed probabilities that a process or material meets specifications. The assumptions underlying this approach and example follow. For additional details see Burr (1976).

- The standard deviation of permeability measurements is unknown and will be estimated from the sample data.
- The probability distribution of permeability measurements is normal.
- The acceptance quality limit (p_1) is 0.2 percent, i.e., it is acceptable to have 0.2 percent of the samples with permeability exceeding the criteria of 1×10^{-8} cm/s.
- The unacceptable quality limit (p_2) is 2 percent, i.e., it is unacceptable to have 2 percent or more of the samples with permeability exceeding 1×10^{-8} cm/s.
- The probability of rejecting the liner as unacceptable (based on the sample) when it is indeed acceptable (0.2 percent or less of all potential soil samples from the total liner have permeability exceeding 1×10^{-8} cm/s) should not exceed 0.10.
- The probability of accepting the liner (based on the sample results) when it is not acceptable (2 percent or more of all potential soil samples from the total liner have permeability exceeding 1×10^{-8} cm/s) should not exceed 0.01.

Based on these assumptions, the required sample size is determined as follows:

$$n = (q^2 + 2) / 2 \times [(z_a + z_b) / (z_{p1} - z_{p2})]^2$$

= sample size

where

z_a = standard normal deviate corresponding to the one tailed probability of rejecting an acceptable liner. ($z_a = 1.282$ corresponding to 0.10 in the example.)

z_b = standard normal deviate corresponding to the one tailed probability of accepting an unacceptable liner. ($z_b = 2.326$ corresponding to 0.01 in the example.)

z_{p1} = standard normal deviate corresponding to the one tailed acceptable proportion (probability) of failures. ($z_{p1} = 2.88$ corresponding to 0.002 in the example.)

z_{p2} = standard normal deviate corresponding to the one tailed unacceptable proportion (probability) of failures. ($z_{p2} = 2.055$ corresponding to 0.02 in the example.)

$$q = (z_a \times z_{p2} + z_b \times z_{p1}) / (z_a + z_b)$$

($q = 2.5869$ in the example)

Hence, the required sample size is:

$$n = [(2.5869^2 + 2) / 2] \times [(1.282 + 2.326) / (2.88 - 2.055)]^2$$
$$= 83.1216 \text{ or } 84 \text{ sampling units.}$$

The plan, or strategy, is to select a sample of 84 soil sample elements and to measure the permeability of each. Compute the mean "avg" and standard deviation "s" of these measurements. Acceptance or rejection of the liner should be based on the following criteria:

$$\text{avg} + q \times s \leq U \text{ accept}$$

$$\text{avg} + q \times s > U \text{ reject}$$

where

U = acceptable permeability value (1×10^{-8} cm/s).

Hence, if the mean and standard deviation of the 84 permeability measurements are 1×10^{-9} cm/s and 1.4×10^{-9} cm/s, the liner would be accepted because 1×10^{-9} cm/s + $2.5869 \times 1.4 \times 10^{-9}$ cm/s = 3.62×10^{-9} cm/s $< 1 \times 10^{-8}$ cm/s.

For other situations, such as when there is a lower specification limit, there are both upper and lower specification limits, and/or there is a reasonable basis for assuming that the measurement variance is known prior to sampling. If so, consult standard statistical quality control texts such as Burr (1976).

2.4.3.2.3 Sequential sampling--All of the sampling strategies and sample size estimates discussed so far (with the possible exception of sample supplementation to reduce variance of sample estimates) assume that the sample size or sampling frequency will be determined prior to initiation of the sampling program (i.e., the data from the sample will not influence these estimates). A sequential sampling strategy does not initially set sampling size or frequency; instead, after each sample element is inspected, a decision is made to accept the block it represents, to reject it, or to inspect another element (i.e., there is not sufficient data to evaluate the quality of the block). If the quality of the inspected block is very good or very bad, only a minimum number of sample elements will need to be tested to accept or reject the block. If the block is marginal in its quality (i.e., close to the acceptance/rejection criteria), the sequential sampling strategy will require more tests, up to the number required by a fixed sampling strategy. Sequential sampling strategies generally require fewer sampling units to obtain sufficient data for the evaluation of quality than do single sampling strategies and therefore can offer some advantages in terms of cost and time requirements.

The general approach to sequential sampling is to determine after selection and testing of each sample unit if an evaluation can be performed with acceptable precision. If so, the sampling process is terminated; if not, another sample unit is selected. Hence, if the test results are very uniform and at the levels originally hypothesized (or desired) or if the results deviate markedly from the hypothesized (or desired) levels, a decision to accept or reject the material or process can be made with few sample units. If, however, the data are highly variable and reasonably close to the rejection criteria, a larger sample will be required before a decision can be made. Hence, the sample size is a variable in this type of sampling design. For more information on sequential sampling, the reader is referred to Burr (1976).

2.4.3.2.4 Assessment of sources of variability--The previous discussion on statistical sampling strategies has not considered the fact that variability in test results can result from errors associated with the testing procedure and thus may not reflect the true variability of the parameter being measured. To apply a statistical sampling strategy, it is important to determine the sources of variability present in the measurement of the parameter in question. This requires determination of the precision and accuracy of the test methods used for measurement and consideration of these factors in the analysis of data variability.

Unfortunately, precision and accuracy of many of the test methods that are critical to evaluating the construction quality of a hazardous waste land disposal facility (e.g., field and laboratory permeability of a soil liner) are not presently known. This necessitates estimation of these parameters if statistical sampling strategies are to be properly applied. This estimation may be done by judgment if the engineer designing the sampling strategy is very familiar with the test method in question, but it is better to base these estimates on replicate measurements of batches of the material in question that are known to be uniform with respect to the properties being measured. A replicate measurement is defined as one in which every conceivable factor that could influence measurement results is the same as in the original test. Test replication can be used to determine repeatability, or single operator precision.

If multiple operators will be conducting a test, or if other factors influencing test results (e.g., weather conditions) are likely to vary during the course of testing, test reproducibility also should be assessed. Test reproducibility can be assessed by retaining an area or volume of the tested material, which is uniform in its properties, for the duration of construction. This material may be sampled and tested regularly throughout construction to determine if measurement techniques have changed. In addition, if a change in testing conditions occurs that could have an effect on test results (e.g., a different test operator or a change in weather conditions), the effect of this change may be assessed by conducting tests on the retained material.

2.4.4 Treatment of Outliers

Occasionally, in a supposedly homogeneous sample, one of the test values appears to deviate markedly from the remainder of the sample. Such a value is called an outlier. Rules for rejection of outliers are based on confidence level criteria. Standard practice for dealing with outlying observations is contained in ASTM (1985b) E 178. This practice may be applied only to random, statistically evaluated samples. According to ASTM E178, two alternative explanations for outliers are of interest:

- An outlying observation may be an extreme manifestation of the random variability inherent in the data. In this case, the value should be retained and processed with the other observations in the sample.
- An outlying observation may result from gross deviation from the test procedure or an error in calculating or recording the numerical value. In this case, the outlier may or may not be rejected. If used in the subsequent analyses, the outlying values may be recognized as being from a different population than the other sample values.

ASTM E178 provides statistical rules that lead the investigator to look for causes of outliers and decide which of the above alternatives apply so that the most appropriate action may be taken in further data analysis. The procedures used are too extensive to quote in this document, and the reader is referred to ASTM (1985b). For more information concerning available specialized tests for outliers and the assumptions underlying these tests, see Barnett and Lewis (1978) or Dixon and Massey (1957).

2.4.5 Corrective Measures

When material or work is rejected because observations or tests indicate that it does not meet the design specifications, corrective measures must be implemented. For material subject to 100-percent inspection, substandard material is simply rejected. When workmanship subject to 100-percent inspection is rejected (e.g., synthetic membrane seams), it must be redone until it meets specifications. For material or workmanship subject to judgmental or statistical methods, in question because of CQA inspection personnel observations or test results, additional testing of the component may be necessary prior to rejecting the block of work and specifying corrective measures. This additional testing can help determine the cause of the problem so that it may be avoided in the future. It also will define the extent of the problem so that adequate corrective measures can be specified.

For any facility component, the actual physical means of corrective measures, in the case of noncompliance, is a combined design and construction function. Both of the latter topics are beyond the scope of this document. Regardless of the means of correcting the deficiency, CQA personnel should inspect the correction to ensure that the specified design has been met.

2.4.6 Control Charts

For some materials or processes it may be desirable to maintain records of quality over time. For example, it may be necessary to assess the particle size of truck loads of incoming soils used in preparing the liner. Assuming that the loads are relatively homogeneous (there are no major differences in soil types or moisture content among the loads), a control chart approach might be used. A systematic sampling strategy could be used to select incoming truck loads for analysis, and the test results would be plotted against time. These types of plots provide a means to keep track of the incoming materials so that appropriate action may be taken whenever it is indicated (actions to be taken in response to deviations from the norm should be specified by the design engineer). For some material or properties, deviations in quality in either direction may be important (such as soil moisture content); for others, deviations in only one direction will be of concern (such as soil permeability).

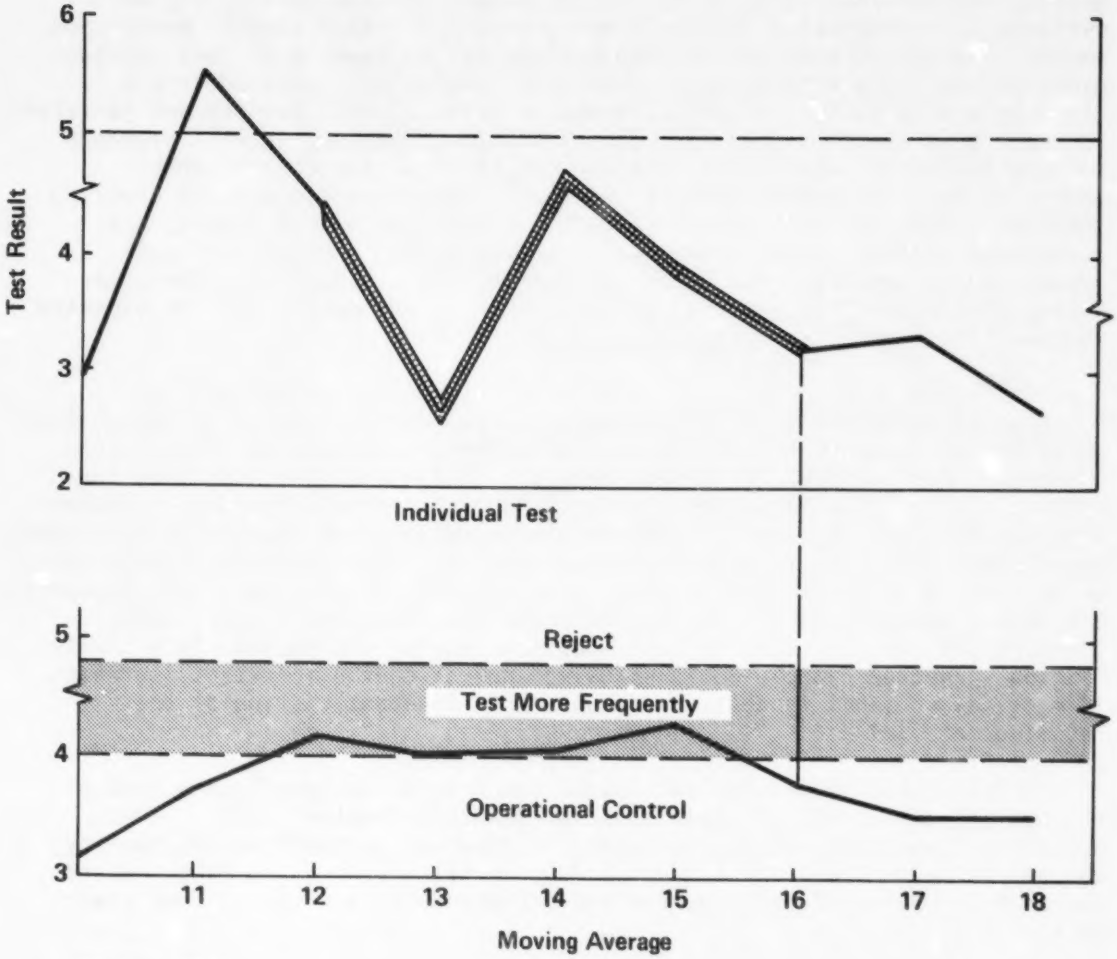
One of the fundamental questions of this approach is: What is an abnormal test result? Upper and lower limits of acceptability about the norm or mean of the test results can be established by assuming that the measurements are normally distributed and setting limits that will include a predetermined proportion of the measurements (usually 90 or 95 percent) or by setting_them at some predetermined level of acceptability (such as a maximum of 10^{-8} level of permeability for soils used as liner material). For those measurements where little is known concerning natural variability and there is no sound basis for setting a level of acceptability, the test results from experimental sites (e.g., test fills) could be used to establish a norm and usual variation that could be used for setting up the control chart.

It will likely be advisable to revise the control chart limits as tests are performed on the disposal site; these changes should only be done with the concurrence of the CQA officer and the design engineer. All measurements that fall outside the established limits should be referred to the CQA officer, who will attempt to identify the cause for deviation and the appropriate action to rectify the problem; specific responses to deviation should be specified by the design engineer. The usual practice in quality control statistics is to record summary results (means, standard deviations, or ranges) of multiple measurements for each sample, where each sample consists of a series of sample elements; an example of this approach might be used in a design where large soil samples are selected from a liner by a grid system and multiple measurements of soil density are performed for each grid section. For land disposal sites, however, it will probably be more common to record individual measurements on the control chart (Burr, 1976). The sample size/frequency (number of sample unit or sampling interval), sampling unit (e.g., truck load, grid section of liner), and acceptance criteria must be determined by the design engineer and will depend on the specific goal of an assessment, the site-specific characteristics of a particular material or process to be evaluated, and the expected variability of the test data.

Control charts can be used to monitor the quality of material or constructed work over time, providing a useful record of material variability or of the performance of a construction contractor as the facility is constructed. For example, the owner/operator, design engineer, construction contractor, or CQA officer may use these charts to detect trends in workmanship quality that may not be apparent when comparing the results of individual tests. With the use of control charts, declines in workmanship quality can be correlated with potential causes (e.g., weather conditions), and appropriate corrective measures (e.g., changes in operating procedures, additional training programs, or more frequent testing) may be implemented in a timely fashion. Another example would be using control charts to detect increases in material variability that may require more frequent testing of the incoming material.

Properly maintained control charts can provide an immediate review of the quality of a block of material or workmanship (Beaton, 1968). They provide a convenient and concise means of documenting construction quality and may serve to summarize a great volume of test reports and other records, speeding up review of test records and acceptance of a block of completed work.

An example of a control chart is presented in Figure 2-3. In the upper graph, individual test results for a block of material are plotted in chronological order. In the lower graph, a moving average of the test results is plotted on a graph. If the average test results are in the shaded area (approaching the rejection level), more frequent testing is required to accept the lot. Below the shaded area, the lot is accepted; above it, it is rejected. If statistical sampling methods are used, the acceptance/rejection levels and the levels requiring more testing may be determined by statistical methods, as described earlier in this section.



(Beaton, 1968)

Figure 2-3. Control charts: individual and moving average.

Kotzias and Stamatopoulos (1975) used three types of control charts with judgmental sampling methods to evaluate construction quality for an earthen dam. Simple quality control charts were used to evaluate day-to-day construction performance. These charts plotted daily averages and ranges of test results over the course of the construction period and are valuable chronological records, but are not formal control charts. Rejection charts (Figure 2-4) cumulatively plot the total number of rejected tests and the magnitude of each rejected result against the total number of test results (retests excluded). These charts reveal the rejection rate and the severity of defects in the rejected material (compacted earthfill). Finally, frequency diagrams (Figure 2-5) were plotted for whole components or for sampling blocks. These diagrams were presented in pairs, i.e., defects included, retests excluded (before remedial action), and defects excluded, retests included (as accepted). These charts are bar diagrams plotting number of test results against test results (Figure 2-5). Evaluated jointly with rejection charts (Figure 2-4), they provide a way of determining the overall importance of defects and remedial measures.

Although control charts may be used with either judgmental or statistical sampling, when used with judgmental methods they reflect the bias inherent in the judgmental sampling. Thus, the "as accepted" frequency diagrams may not accurately represent the quality of the completed work when used with judgmental sampling, but they will for a sampling strategy determined by statistical methods.

For more information concerning the use of control charts, see standard texts concerning quality control such as Duncan (1959), Burr (1976), or Grant (1964).

2.5 DOCUMENTATION

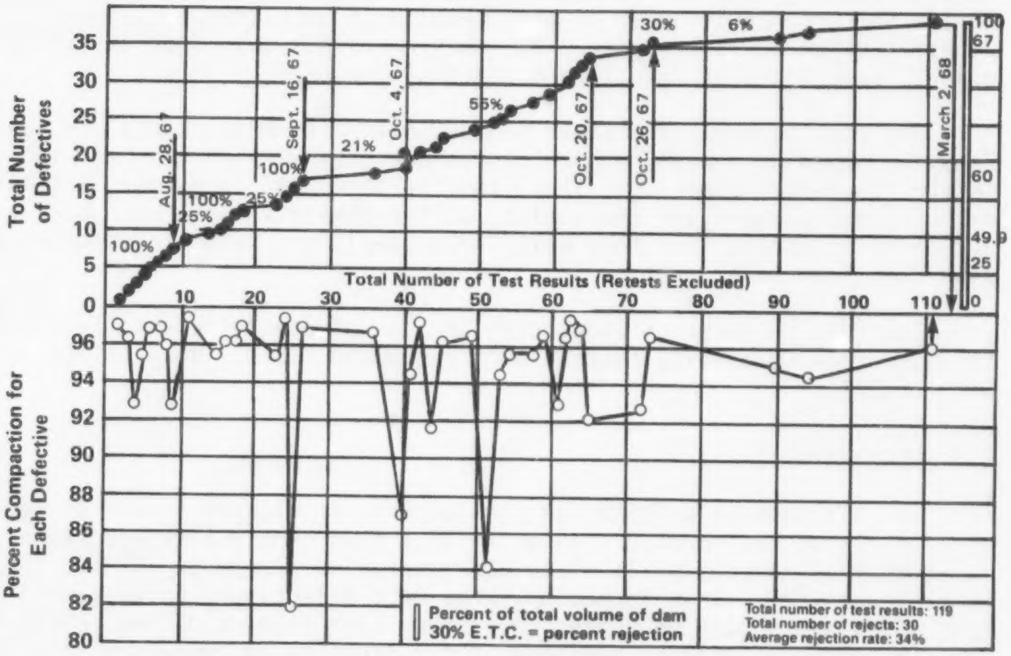
The ultimate value of a CQA plan depends to a large extent on recognition of all of the construction activities that should be inspected and the assignment of responsibilities to CQA inspection personnel for the inspection of each activity. This is accomplished most effectively by documenting CQA activities and should be addressed as the fifth element of the CQA plan. The CQA personnel will be reminded of the items to be inspected, and will note, through required descriptive remarks, data sheets, and checklists signed by them, that the inspection activities have been accomplished.

2.5.1 Daily Recordkeeping

Standard daily reporting procedures should include preparation of a summary report with supporting inspection data sheets and, when appropriate, problem identification and corrective measures reports.

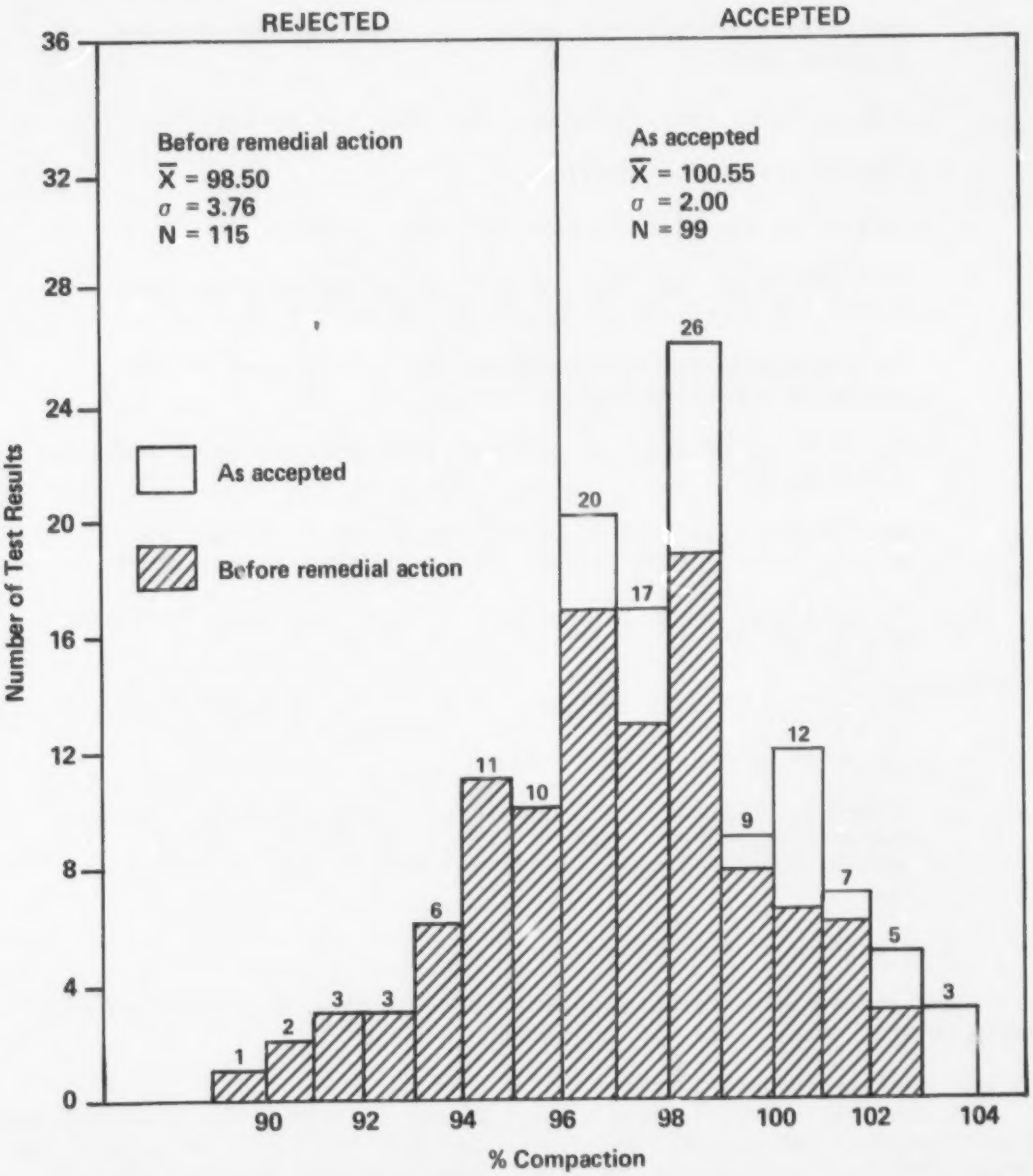
2.5.1.1 Daily Summary Report--

A summary report should be prepared daily by the CQA officer. This report provides the chronologic framework for identifying and recording all other reports. At a minimum, the summary reports should include the following information (Spigolon and Kelley, 1984):



(Beaton, 1968)

Figure 2-4. Rejection chart: density measurements for dam core compaction control.



From Kotzias and Stamatopoulos, 1975

Figure 2-5. Frequency diagram: density measurements for dam core compaction control.

- Unique identifying sheet number for cross-referencing and document control
- Date, project name, location, and other identification
- Data on weather conditions
- Reports on any meetings held and their results
- Unit processes, and locations, of construction under way during the timeframe of the daily summary report
- Equipment and personnel being worked in each unit process, including subcontractors
- Descriptions of areas or units of work (blocks) being inspected and documented
- Description of offsite materials received, including any quality verification (vendor certification) documentation
- Calibrations, or recalibrations, of test equipment, including actions taken as a result of recalibration
- Decisions made regarding approval of units of material or of work (blocks), and/or corrective actions to be taken in instances of substandard quality
- Unique identifying sheet numbers of inspection data sheets and/or problem reporting and corrective measures reports used to substantiate the decisions described in the preceding item
- Signature of the CQA officer.

Items above may be formulated into site-specific checklists and data sheets so that details are not overlooked.

2.5.1.2 Inspection Data Sheets--

All observations, and field and/or laboratory tests, should be recorded on an inspection data sheet. Required data to be addressed for most of the standardized test methods are included in the pertinent AASHTO (1983) and ASTM (1985a) Standards. Examples of field and/or laboratory test data sheets are given in Department of the Army (1970, 1971) manuals and in Spigolon and Kelley (1984).

Because of their highly specific nature, no standard format can be given for data sheets to record observations. Recorded observations may take the form of notes, charts, sketches, photographs, or any combination of these. Where possible, a checklist may be useful to ensure that no pertinent factors of a specific observation are overlooked.

At a minimum, the inspection data sheets should include the following information (Spigolon and Kelly, 1984):

- Unique identifying sheet number for cross-referencing and document control
- Description or title of the inspection activity
- Location of the inspection activity or location from which the sample increment was obtained
- Type of inspection activity; procedure used (reference to standard method when appropriate)
- Recorded observation or test data, with all necessary calculations
- Results of the inspection activity; comparison with specification requirements
- Personnel involved in the inspection activity
- Signature of the appropriate CQA inspection personnel and concurrence by the CQA officer.

Items above may be formulated into site-specific checklists and data sheets so that details are not overlooked.

2.5.1.3 Problem Identification and Corrective Measures Reports--

A problem is defined herein as material or workmanship that does not meet the specified design. Problem Identification and Corrective Measures Reports should be cross-referenced to specific inspection data sheets where the problem was identified. At a minimum, they should include the following information:

- Unique identifying sheet number for cross-referencing and document control
- Detailed description of the problem
- Location of the problem
- Probable cause
- How and when the problem was located (reference to inspection data sheets)
- Estimation of how long problem has existed
- Suggested corrective measure

- Documentation of correction (reference to inspection data sheets)

- Final results

- Suggested methods to prevent similar problems

- Signature of the appropriate CQA inspection personnel and concurrence by the CQA officer.

In some cases, not all of the above information will be available or obtainable. However, when available, such efforts to document problems could help to avoid similar problems in the future.

Upon receiving the CQA officer's written concurrence, copies of the report should be sent to the design engineer and the facility owner/operator for their comments and acceptance. These reports should not be submitted to the permitting agency at that time unless they have been specifically requested. However, a summary of all data sheets and reports may be required by the permitting agency upon completion of construction.

2.5.2 Photographic Reporting Data Sheets

Photographic reporting data sheets also may prove useful. Such data sheets could be cross-referenced or appended to inspection data sheets and/or problem identification and corrective measures reports. At a minimum, photographic reporting data sheets should include the following information:

- A unique identifying number on data sheets and photographs for cross-referencing and document control

- The date, time, and location where the photograph was taken and weather conditions

- The size, scale, and orientation of the subject matter photographed

- Location and description of the work

- The purpose of the photograph

- Signature of the photographer and concurrence of the CQA officer.

These photographs will serve as a pictorial record of work progress, problems, and corrective measures. They should be kept in a permanent protective file in the order in which they were taken. The file should contain color prints; negatives should be stored in order in a separate file.

2.5.3 Block Evaluation Reports

Within each inspection block, there may be several quality characteristics, or parameters, that are specified to be observed or tested, each by a different observation or test, with the observations and/or tests recorded on different data sheets. At the completion of each block, these data sheets should be organized into a block evaluation report. These block evaluation reports may then be used to summarize all of the site construction activities.

Block evaluation reports should be prepared by the CQA officer and, at a minimum, include the following information (Spigolon and Kelley, 1984):

- Unique identifying sheet number for cross-referencing and document control
- Description of block (use project coordinate system to identify areas, and appropriate identifiers for other units of material or work)
- Quality characteristic being evaluated; references to design criteria, plans, and specifications
- Sampling requirements for the inspected block and how they were established
- Sample item locations (describe by project coordinates or by a location sketch on the reverse of the sheet)
- Inspections made (define procedure by name or other identifier; give unique identifying sheet number for inspection data sheets)
- Summary of inspection results (give block average and, if available, the standard deviation for each quality characteristic)
- Define acceptance criteria (compare block inspection data with design specification requirements; indicate compliance or noncompliance; in the event of noncompliance, identify documentation that gives reasons for acceptance outside of the specified design)
- Signature of the CQA officer.

2.5.4 Acceptance of Completed Components

All daily inspection summary reports, inspection data sheets, problem identification and corrective measures reports, and block evaluation reports should be reviewed by the CQA officer. The documentation should be evaluated and analyzed for internal consistency and for consistency with similar work.

Timely review of these documents will permit errors, inconsistencies, and other problems to be detected and corrected as they occur, when corrective measures are easiest.

The above information should be assembled and summarized into periodic Acceptance Reports. The reports should indicate that the materials and construction processes comply with the specified design. These reports should be included in project records, submitted to the facility owner/operator, and, if requested, submitted to the permitting agency.

2.5.5 Final Documentation

At the completion of the project, the facility owner/operator should submit a final report to the permitting agency. This report should include all of the daily inspection summary reports, inspection data sheets, problem identification and corrective measures reports, block evaluation reports, photographic reporting data sheets, acceptance reports, deviations from design and material specifications (with justifying documentation), and as-built drawings. This document should be certified correct and included as part of the CQA plan documentation.

2.5.5.1 Responsibility and Authority--

The final documentation should reemphasize that areas of responsibility and lines of authority were clearly defined, understood, and accepted by all parties involved in the project. Signatures of the facility owner/operator, design engineer, CQA officer, and construction contractor should be included as confirmation that each party understood and accepted the areas of responsibility and lines of authority and performed their function(s) in accordance with the CQA plan.

2.5.5.2 Relationship to Permitting Agencies--

Final documentation submitted to the permitting agency as part of the CQA plan documentation does not sanction the CQA plan as a guarantee of facility construction and performance. Rather, the primary purpose of the final documentation is to improve confidence in the constructed facility through written evidence that the CQA plan was implemented as proposed and that the construction proceeded in accordance with design criteria, plans, and specifications.

2.5.6 Document Control

The CQA plan and all CQA documentation should be maintained under a document control procedure. This indexing procedure should provide for convenient replacement of pages in the CQA plan, thereby not requiring a revision to the entire document, should identify the revision status of the CQA documents, and should enable the CQA documents to be organized in terms of their relationship to each other, the CQA plan, and the time and location of the materials and/or workmanship that they represent.

Each page of the CQA plan should have the following indexing information in the top right corner:

- Section no.
- Revision no.
- Date (of revision)
- Page no. (e.g., 1 of 12) by section.

The table of contents should follow the same structure as the text, including the above information for each section of the document. This will allow convenient revision of the document and will help ensure that the most current revision of the plan is in use.

For CQA documentation, a control scheme should be used to organize and index all CQA documents. This scheme should be designed to allow easy access to all CQA documents and should enable a reviewer to identify and retrieve original data sheets for any completed block of work or facility component. This will require a unique identifying number for each CQA record and an indexing scheme to relate summary reports to the original inspection data sheets. For example, each daily summary report should clearly identify the inspection data sheets upon which it is based. Problem identification and corrective measures reports also should identify the pertinent inspection data sheets that identified the substandard materials or workmanship, and inspection data sheets that document construction quality after implementation of the corrective measures. The document control scheme to be used to organize CQA records for a specific site should be described in detail in the CQA plan.

2.5.7 Storage of Records

During the construction of a hazardous waste land disposal facility, the CQA officer should be responsible for all facility CQA documents. This includes the CQA officer's copy of the design criteria, plans, and specifications, the CQA plan, and the originals of all the data sheets and reports. Duplicate records may be kept at another location to avoid loss of this information if the originals are destroyed.

Once facility construction is complete, the document originals should be stored by the owner/operator in a manner that will allow for easy access while still protecting them from any damage. An additional copy should also be kept at the facility if this is in a different location from the owner/operator's files. A final copy should be kept by the permitting agency in a publicly acknowledged repository. All documentation should be maintained through the operating and postclosure monitoring periods of the facility.

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APPENDIX A. INSPECTION METHODS USED DURING THE CONSTRUCTION OF HAZARDOUS WASTE LAND DISPOSAL FACILITIES

Facility component	Factors to be inspected	Inspection methods	Test method reference[a]
Foundation	Removal of unsuitable materials	Observation	NA
	Proof rolling of subgrade	Observation	NA
	Filling of fissures or voids	Observation	NA
	Compaction of soil backfill	(See low-permeability soil liner component)	
	Surface finishing	Observation	NA
	Sterilization	Supplier's certification and observation	NA
	Slope	Surveying	NA
	Depth of excavation	Surveying	NA
	Seepage	Observation	NA
	Soil type (index properties)	Visual-manual procedure	ASTM D2488
		Particle size analysis	ASTM D422
		Atterberg limits	ASTM D4318
		Soil classification	ASTM D2487
	Cohesive soil consistency (field)	Penetration tests	ASTM D3441
		Field vane shear test	ASTM D2573
		Hand penetrometer	Horslev, 1943
		Handheld torvane	Lanz, 1968
		Field expedient unconfined compression	TM 5-530 (U.S. Dept. of Army, 1971)
	Strength (laboratory)	Unconfined compressve strength	ASTM D2166
		Triaxial compression	ASTM D2850
		Unconfined compressive strength for soil-cement	ASTM D1633
Dikes	Dike slopes	Surveying	NA
	Dike dimensions	Surveying; observations	NA
	Compacted soil	(See low-permeability soil liner component)	
	Drainage system	(See leachate collection system component)	
	Erosion control measures	(See cover system component)	

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[a] For all test methods, the most up-to-date standard should be used.

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
Low-permeability soil liner	Coverage	Observation	NA
	Thickness	Surveying; measurement	NA
	Clod size	Observation	NA
	Tying together of lifts	Observation	NA
	Slope	Surveying	
	Installation of protective cover	Observation	NA
	Soil type (index properties)	Visual-manual procedure	ASTM D2488
		Particle size analysis	ASTM D422
		Atterberg limits	ASTM D4318
		Soil classification	ASTM D2487
	Moisture content	Oven-dry method	ASTM D2216
		Nuclear method	ASTM D3017
		Calcium carbide (speedy)	AASHTO T217
		Frying pan (alcohol or gas burner)	Spigolon & Kelley (1984)
	In-place density	Nuclear methods	ASTM D2922
		Sand cone	ASTM D1556
		Rubber balloon	ASTM D2167
		Drive cylinder	ASTM D2937
	Moisture-density relations	Standard proctor	ASTM D698
		Modified proctor	ASTM D1557
		Soil-cement M-D test	ASTM D558
	Strength (laboratory)	Unconfined compressive strength	ASTM D2166
		Triaxial compression	ASTM D2850
		Unconfined compressive strength for soil-cement	ASTM D1633
	Cohesive soil consistency (field)	Penetration tests	ASTM D3441
		Field vane shear test	ASTM D2573
		Hand penetrometer	Horslev, 1943
		Handheld torvane	Lanz, 1968
		Field expedient unconfined compression	TM 5-530 (U.S. Dept. of Army, 1971)
	Permeability (laboratory)	Fixed wall	EPA, 1983. SW-870
		Flexible wall	Daniel et al., 1984 Daniel et al., 1985 SW-846 Method 9100 (EPA, 1984)
	Permeability (field)	Large diameter single-ring infiltrometer	Day and Daniel, 1985
		Sai-Anderson infiltrometer	Anderson et al., 1984

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
	Susceptibility to frost damage	Susceptibility classification	Chamberlin, 1981
		Soil-cement freeze-thaw test	ASTM D560
	Volume change	Consolidometer (undisturbed or remolded sample)	Holtz, 1965
		Soil-cement wet-dry test	ASTM D559
		Soil-cement freeze-thaw test	ASTM D560
Flexible membrane liners	Thickness	Thickness of unreinforced plastic sheeting (paragraph 8.1.3, deadweight method--specifications for nonrigid vinyl chloride plastic sheeting	ASTM D1593
		Thickness of reinforced plastic sheeting (testing coated fabrics)	ASTM D751
	Tensile properties	Tensile properties of rigid thick plastic sheeting (standard method test for tensile properties of plastics)	ASTM D638
		Tensile properties of reinforced plastic sheeting (Grab method A--testing coated fabrics)	ASTM D751
		Tensile properties of thin plastic sheeting	ASTM D882
	Tear strength	Tear strength of reinforced plastic sheeting (modified tongue tear method B--testing coated fabrics)	ASTM D751
		Tear strength of plastic sheeting (Die C--test method for initial tear resistance of plastic film and sheeting)	ASTM D1004
	Bonding materials	Manufacturer's certification	NA
	Bonding equipment	Manufacturer's certification	NA
	Handling and storage	Observation	NA

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
	Seaming	Ply adhesion of reinforced synthetic membranes, bonded seam strength in peel (machine method, Type A test methods for rubber properties, adhesion to flexible substrate)	ASTM D413 ASTM D4437
		Bonded seam strength in shear of reinforced plastic sheeting (modified grab method A--testing coated fabrics)	ASTM D751
		Bonded seam strength in shear of unreinforced plastic sheeting (modified)	ASTM D3083
	Sealing around penetrations	Observation	NA
	Anchoring	Observation	NA
	Coverage	Observation	NA
	Installation of upper bedding layer	Observation	NA
Leachate collection system			
• Granular drainage and filter layers	Thickness	Surveying; measurement	NA
	Coverage	Observation	NA
	Soil type	Visual-manual procedure Particle size analysis Soil classification	ASTM D2488 ASTM D422 ASTM D2487
	Density	Nuclear methods Sand cone Rubber balloon	ASTM D2922 ASTM D1556 ASTM D2167
	Permeability (laboratory)	Constant head	ASTM D2434
• Synthetic drainage and filter layers	Material type	Manufacturer's certification	NA
	Handling and storage	Observation	NA
	Coverage	Observation	NA

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
	Overlap	Observation	NA
	Temporary anchoring	Observation	NA
	Folds and wrinkles	Observation	NA
	Geotextile properties	Tensile strength	Horz (1984)
		Puncture or burst resistance	Horz (1984
		Tear resistance	Horz (1984)
		Flexibility	Horz (1984)
		Outdoor weatherability	Horz (1984)
		Short-term chemical resistance	Horz (1984)
		Fabric permeability	Horz (1984)
		Percent open area	Horz (1984)
· Pipes	Material type	Manufacturer's certification	NA
	Handling and storage	Observation	NA
	Location	Surveying	NA
	Layout	Surveying	NA
	Orientation of perforations	Observation	NA
	Jointing		
	· Solid pressure pipe	Hydrostatic pressure test	Section 4, AWWA C600
	· Perforated pipe	Observation	NA
· Cast-in-place concrete structures	Sampling	Sampling fresh concrete	ASTM C172
	Consistency	Slump of portland cement concrete	ASTM C143
	Compressive strength	Making, curing, and testing concrete specimens	ASTM C31
	Air content	Pressure method	ASTM C231
	Unit weight, yield, and air content	Gravimetric method	ASTM C138
	Form work inspection	Observation	NA

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
· Electrical and mechanical equipment	Equipment type	Manufacturer's certification	NA
	Material type	Manufacturer's certification	NA
	Operation	As per manufacturer's instructions	NA
	Electrical connections	As per manufacturer's instructions	NA
	Insulation	As per manufacturer's instructions	NA
	Grounding	As per manufacturer's instructions	NA
Cover system			
· Cover foundation	Waste placement records/ waste placement process	Observation	NA
	Soil backfill	(See foundation component)	
· Low-permeability soil barrier	(See low-permeability soil liner component)		
· Flexible membrane barrier	(See flexible membrane liner component)		
· Bedding layer	(See flexible membrane liner component)		
· Drainage and gas venting layers	(See leachate collection system component)		
· Topsoil and vegetation (erosion control measures)	Thickness	Surveying	NA
	Slope	Surveying	NA
	Coverage	Observations	NA
	Nutrient content	Various procedures	Page, 1982
	Soil pH	Soil pH; lime requirement	Page, 1982
	Soil type; moisture content	(See low-permeability soil liner component)	
	Vegetation type	Supplier's certification; observations	NA
	Seeding time	Supplier's recommendations; observations	NA

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